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Becker, Thomas Ralph ; Hartenfels, Swen ; Klug, Christian ; Aboussalam, Zhor Sar ; Afhüppe, Lukas

Abstract: Highlights - Lower Famennian black shales with (primary) pyritic cheiloceratids and large tree logs. - Middle Famennian goniatite shales at Madène el Mrakib. - Anoxic Lower and Upper Annulata Events. - Upper Famennian rich Platyclymenia faunas. - Hypoxic Dasberg Crisis Interval, followed by rich Gonioclymenia faunas. - Uppermost Famennian Wocklumeria nodules. - Hangenberg Black Shale of Mrakib with unique preservation of goniatite and clymeniid jaws. - Global Hangenberg Crisis Interval with regressive, thick clastic wedges. - Lower Tournaisian goniatite shales with rich Acutimitoceras and Gattendorfia faunas at Tazoult and Bou Tlidat. - The unique topmost lower Tournaisian Kahlacanites fauna at Bou Tlidat. - Global Lower Alum Shale Event followed by basal middle Tournaisian Goniocyclus faunas.

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The cephalopod-rich Famennian and Tournaisian of the Aguelmous Syncline (southern Maïder)

RALPH THOMAS BECKER [1], SVEN HARTENFELS [1], CHRISTIAN KLUG [2], ZHOR SARAH ABOUSSALAM [1] & LUKAS AFHÜPPE [1]

Fig. 1: View from the east on the low hills at the northern end of Jebel Mrakib or Madène el Mrakib, southern Maïder, with the middle Famennian in the lower part and big sandstone blocks of the uppermost Famennian Aguelmous Formation at the top.

Highlights

- **Lower Famennian black shales with (primary) pyritic cheiloceratids and large tree logs.**
- **Middle Famennian goniatite shales at Madène el Mrakib.**
- **Anoxic Lower and Upper *Annulata* Events.**
- **Upper Famennian rich *Platyclymenia* faunas.**
- **Hypoxic Dasberg Crisis Interval, followed by rich *Gonioclymenia* faunas.**
- **Uppermost Famennian *Wocklumeria* nodules.**
- **Hangenberg Black Shale of Mrakib with unique preservation of goniatite and clymeniid jaws.**
- **Global Hangenberg Crisis Interval with regressive, thick clastic wedges.**
- **Lower Tournaisian goniatite shales with rich *Acutimitoceras* and *Gattendorfia* faunas at Tazoult and Bou Tlidat.**
- **The unique topmost lower Tournaisian *Kahlacanites* fauna at Bou Tlidat.**
- **Global Lower Alum Shale Event followed by basal middle Tournaisian *Goniocyclus* faunas.**

1. Introduction

The upper/uppermost Famennian ammonoids of the Aguelmous Syncline in the southern Maïder, from the region around Fezzou, have become world-famous because they are sold in rock shops around the globe. Teaching collections of many universities contain today goethitic or hematitic (originally

[1] Prof. Dr. Ralph Thomas Becker, Dr. Sven Hartenfels, Dr. Zhor Sarah Aboussalam, B.Sc. Lukas Afhüppe, Institut für Geologie und Paläontologie, Westfälische Wilhelms-Universität Münster, Corrensstr. 24, 48149 Münster, Germany, rbecker@uni-muenster.de, shartenf@uni-muenster.de, taghanic@uni-muenster.de, l_afhu01@uni-muenster.de; [2] Prof. Dr. Christian Klug, Paläontologisches Institut und Museum, Universität Zürich, Karl Schmid-Strasse 4, CH-8600 Zürich, Switzerland, chklug@pim.uzh.ch.

pyritic) prionoceratids, discoclymeniids (Fig. 2), cymaclymeniids, or other regionally common groups. Therefore, it was easy for the infamous V. J. GUPTA to obtain such specimens and to lure H. K. ERBEN (Bonn) into a joint publication on the alleged first Upper Devonian ammonoids from the Himalaya region of India (GUPTA & ERBEN 1983; TALENT 1989, 1990; TALENT el al. 1988, 1989).

Fig. 2: Example for an upper Famennian goniatite of the Fezzou region that made it to many rock shops throughout the world (probably including one that was visited by the infamous V. J. GUPTA): a *Discoclymenia cucullata atlantea* (BECKER 1995, pl. 2, fig. 5, Ü164/4, FU Berlin, max. diameter = 43 mm).

It is kind of sad that the beautiful Famennian ammonoids of the southern Maïder became an important source for one of the main frauds in palaeontology. It is also unfortunate for their investigation that the commercial collecting has removed many of the nicest and largest specimens from the outcrop, especially close to Fezzou. However, in general, it is still possible to collect rich faunas and most taxa. Despite a range of specific publications in recent years, starting with BECKER et al. (1999, 2000), and KORN (1999a, 1999b), there are still several poorly described ammonoid groups and so far un-named new species.

The Aguelmous is a widely visible ridge starting right at the NE end of the Fezzou village and extending for ca. 16 km towards the NE (Fig. 3). It is composed of upper and uppermost Famennian goniatite/clymeniid shales, which include levels with abundant sideritic nodules. The top of the ridge is formed by quartzites of the Aguelmous Formation, which deposited during the global Hangenberg Crisis Interval right below the Devonian/Carboniferous boundary (KAISER et al. 2011, 2016). Lower Tournaisian sand- and siltstones and episodes of hypoxic goniatite shales occupy the gentle back slope and the subsequent plain in the syncline core.

The Aguelmous Ridge forms the NW limb of the wider Aguelmous Syncline, which curves around near the small village Lambidia, running then on strike towards the SW, with the Rich el Mbidia as the eastern equivalent of the Aguelmous Ridge. From there, the syncline structure continues to the S and SE, and approaches with a short interruption the area at Madène el Mrakib, opposite to the famous Aferdou el Mrakib mudmound (KAUFMANN 2001). The latter area is also famous for Middle Devonian biostromes, brachiopods, and trilobite faunas. In the SW, the Aguelmous Syncline is briefly interrupted by the plain of the Fezzou village but the NW limb re-appears at the low hills of Tazoult, where fossiliferous lower Tournaisian strata can be sampled. From there, the Famennian-Tournaisian belt is often interrupted but continues, for example, to the prominent ridge of Rich Bou Kourazia (e.g. BECKER et al. 2002), and beyond (Fig. 3).

Both limbs of the syncline expose a similar succession of marker units and faunas (Fig. 4). Beds dip with 10-15° towards the syncline centre, which is a hamada that coveres top Tournaisian to Viséan strata. Along the ridges, the deep weathering of shales has freed a wealth of ammonoids and other fossils but hillwash led to a frequent contamination of surface collections from faunas of uphill beds, especially when the slope is steep (e.g. BECKER et al. 2000; KORN et al. 2013). Intensive collecting and section logging over many years established a detailed regional ammonoid succession. Marker beds with in-situ mass occurrences of specific taxa, also including placoderm accumulations, trace fossil beds, or fully anoxic black shales (often red/orange shales due to complete pyrite oxidation), are very helpful for the orientation in the field and for correlation.

Apart from ammonoids, the Famennian and Tournaisian of the Aguelmous Syncline became also an important source for brachiopods (especially rhynchonellids; e.g. SARTENAER 1998, 1999, 2000), crinoids (WEBSTER et al. 2005), fossil wood (e.g. MEYER-BERTHAUD et al. 1997, 1999, 2000, 2013), deep-water solitary Rugosa, loxopteriid bivalves (NAGEL-MYERS et al. 2009), trilobites (HAHN et al. 2012), conodonts (HARTENFELS 2011), and shark teeth (DERYCKE et al. 2008). Several other, partly rare fossil groups (e.g. blastoids, conulariids, colonial corals, hyoliths, tabulate corals, orthid brachiopods, nuculoid bivalves, and gastropods) have hardly been studied at all. Unfortunately, this is also true for the very common longi-orthoconic and breviconic cephalopods. For an analysis of complete faunal assemblages see the recent study on alpha diversity and palaeoecology by FREY et al. (2018).

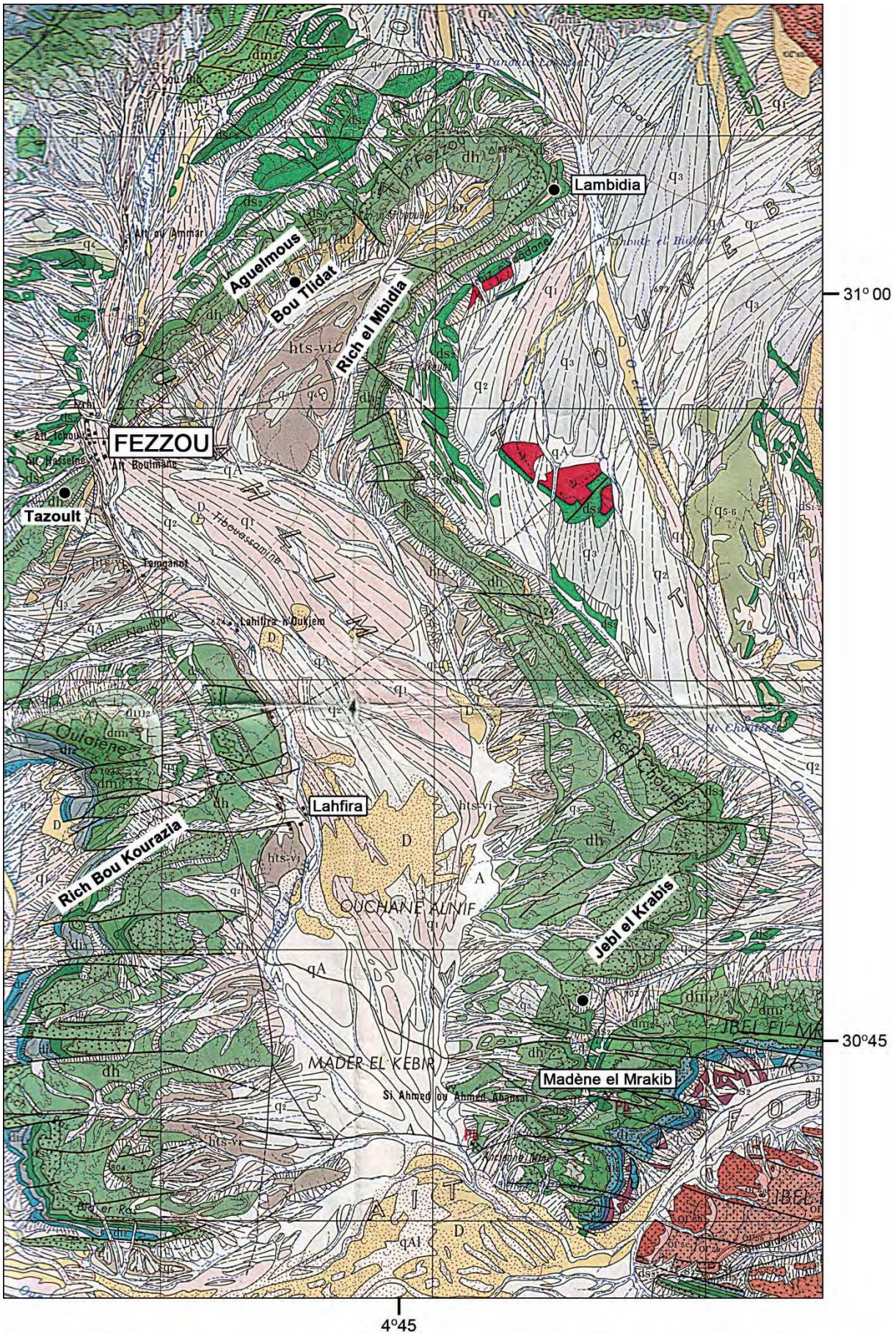

Fig. 3: Geological map of the southern Maïder (extracted from sheet Todrha-Ma´der, 1 : 200.000), showing the Devonian (in green, dm to dh) and Lower Carboniferous (in grey, hts) outcrop belt of the Aguelmous Syncline and of localities mentioned in the text.

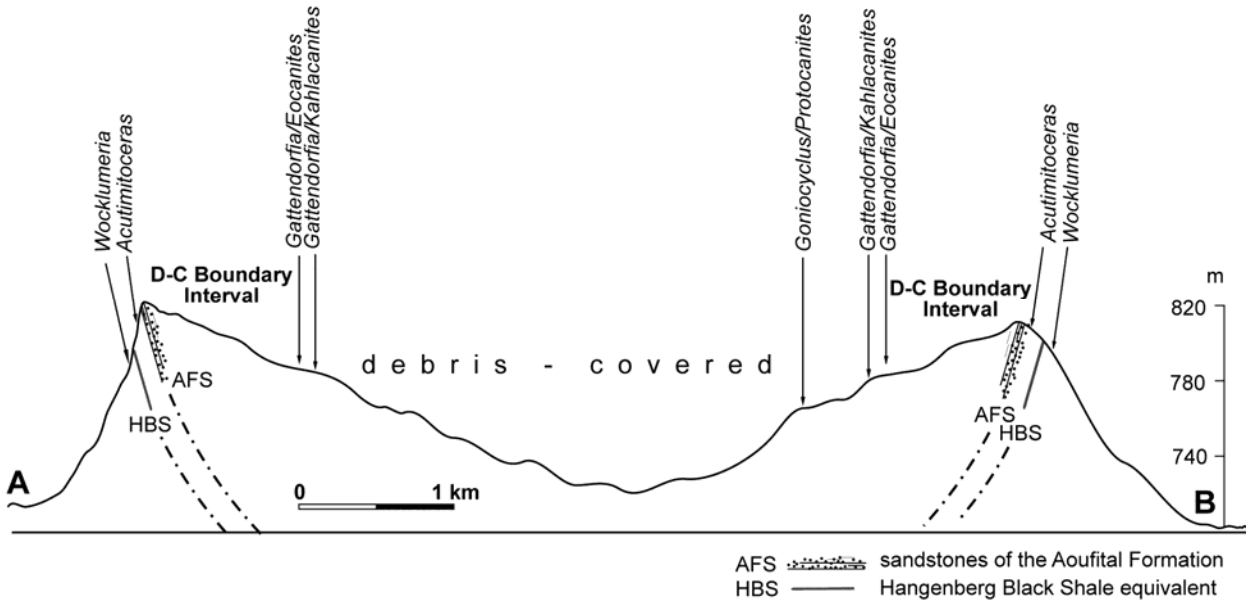

Fig. 4: Schematic cross-section (with strong overheight leading to steep dips) through the Aguelmous Syncline, from near Tizi Ibaouane (A) to the Rich el Mbidia, showing the position of important uppermost Famennian to middle Tournaisian ammonoid levels (extracted from KORN et al. 2007, fig. 4).

2. Palaeogeographic setting

WENDT et al. (1984) assigned the Famennian of the Fezzou region to his Mader Basin, which is characterized by thick, mostly hypoxic, pelagic shales with variably abundant, primary pyritic (secondarily goethitic or hematitic) faunas. They contain levels of black micritic or detrital limestones, which are partly black ammonoid coquinas. In a few cases, cephalopod accumulations at the base of beds indicate death and transport by storm events. Some regressive intervals are characterized by abundant siderite nodules. Red iron crusts indicate episodes of strongly starved sedimentation. Pyrite-rich black shales weather variably to hematite-rich red shale, goethite-rich orange/brown shales, or white to multi-coloured shales with sulphates. Lateral sections show variable thicknesses and fossil abundance of beds, but apart from this, there was not much facies differentiation within the basin, neither in the Famennian, nor in the Carboniferous. WENDT et al. (1984), WENDT (1989), and KAISER et al. (2011) emphasized the sudden change from pelagic to deltaic/prodeltaic facies during the global Hangenberg Regression just below the Devonian-Carboniferous boundary. This occurred very similarly in the topmost Famennian of the Tafilalt and Maïder. However, the Maïder Basin experienced an earlier return of fossiliferous pelagic facies than the southern Tafilalt Platform. The reconstructed current directions were from the SW to NE (DOPIERALSKA 2009).

3. Previous Research

The following extensive compilation concentrates on the Famennian to Tournaisian of the Aguelmous Syncline. Starting with LE MAITRE (1939), numerous other studies dealt with the Emsian to Frasnian strata of the Maïder, including Givetian biostromes and the peculiar mudmounds of Aferdou el Mrakib (KAUFMANN 1998).

CLARIOND (1935): First record of the rich upper Famennian ammonoids of the Aguelmous NE Fezzou, listing 10 different species, followed in the plain, a few km to the E of Fezzou, by a supposed Tournaisian fauna with *Muensteroceras*.

TERMIER & TERMIER (1950a): Description of the rhynchonellid *Calvinaria undulata*, including an upper Famennian specimen from the Fezzou region, which was later selected as the lectotype of the species (see *Pseudoleiorhynchus undulatus* in DROT 1964).

TERMIER & TERMIER (1950b): Illustration of various ammonoids from Fezzou, Aguelmous, Taourirt, and "Merakib": *Sporadoceras orbiculare, Sp. posthumum* [now *Posttornoceras*], "*Imitoceras intermedium*", *Discoclymenia cucullata*, "*Rectoclymenia* cf. *subflexuosa*" [if correct, the only known specimen of the genus from North Africa], "*Varioclymenia enkebergensis*" [a ribbed *Protactoclymenia*], *Cyrtoclymenia angustiseptata, Cymaclymenia* "*costata*", *Cyma. striata*, *"Oxyclymenia" undulata*", "*Oxy. subundulata*" and "*Oxy. bisulcata*" [various kosmoclymeniids],

"*Gonioclymenia insignis*" and "*Gonio. pessoides*" [two species of *Kalloclymenia*] .

CHOUBERT et al. (1952): Brief summary of the diverse Famennian ammonoid fauna from near Fezzou, with illustration of a "*Imitoceras intermedium*", a *Cyrtoclymenia angustiseptata*, and an "*Oxyclymenia subundulata*"; new reference to the *Muensteroceras* faunule from the center of the Aguelmous Syncline, assigning it to the (lower) Viséan.

HOLLARD & JACQUEMONT (1956: footnote on p. 23): First record of questionable *Wocklumeria* from the Jebel Aguelmous area.

HOLLARD (1958): Discovery of a lower Tournaisian *Gattendorfia* fauna in the Aguelmous Syncline.

PETTER (1959): Description of some goniatites from the Fezzou region; type locality of *Lobotornoceras delepinei* [CLARIOND mnscr.], now a species of *Gundolficeras* (see BECKER 1995).

PETTER (1960): Text reference to the presence of *Cyrtoclymenia enkebergensis* var. *crassa*, an invalid homonym (KORN & KLUG 2002), at Taourirt-Timelaline (S of Fezzou).

HOLLARD (1963): Stratigraphic chart for the middle Palaeozoic of the Anti-Atlas, showing the fossiliferous shales from around Fezzou overlain by the "Grès d´Aguelmous n-Ou Fezzou".

HOLLARD (1971): Summary of the upper/uppermost Famennien ammonoid succession near Fezzou.

GUPTA & ERBEN (1983): Misuse of purchased ammonoids from the Fezzou area to describe an alleged fauna from the Upper Devonian of the Himalayans (Himachal Pradesh, India).

TALENT et al. (1988, 1989) and TALENT (1989, 1990): Disclosure of the "GUPTA Fraud", with the illustration of ammonoids from southern Morocco ("Erfoud vicinity", in fact more precisely from the Fezzou area), purchased in a Paris rockshop for the comparison with the specimens of GUPTA & ERBEN (1983).

SARTENAER (1989): Reference to a new species of the rhynchonellid genus *Planovatirostrum* from the Fezzou region.

SCHINDLER (1990): Brief description of the Frasnian-Famennian transition at Rich Bou Kourazia SW of Fezzou.

WENDT & BELKA (1991): First record of *Callixylon* drift wood from lower Famennian black shales.

BELKA & WENDT (1992): Use of conodonts from around the Frasnian-Famennian boundary of Madène el Mrakib in a study on conodont biofacies.

KORN (1994): Illustration of various Prionoceratidae (*Prionoceras, Mimimitoceras*, balviids) from the Fezzou region.

BECKER (1995): Description of tornoceratids from several localities around the Aguelmous Syncline, with Rich Bou Kourazia as the type locality of *Planitornoceras pugnax*, the wider Fezzou region as the type locality of *Exotornoceras fezzouense*, and Taourart as the type locality of *?Exotornoceras sylviae* [better a variant/subspecies of *fezzouense*]. First illustration of *Posttornoceras* and *Alpinites* from the region.

MEYER-BERTHAUD et al. (1997, 1999, 2000, 2013), SORIA et al. (2001), DECOMBEIX & MEYER-BERTHAUD (2013), and TANRATTANA et al. (in press): Description of lower Famennian wood logs and root systems from the Madène el Mrakib belonging to the progymnosperms *Callixylon, Archaeopteris,* and *Pietzschia*.

GRIMM (1998): Description of middle Famennian buchiolid bivalves; Madène el Mrakib as type locality for *Glyptohallicardia merakebensis*.

SARTENAER (1998, 1999, 2000): Madène el Mrakib as the type locality of the deep-water rhynchonellids *Hadyrhyncha meridionalis, Tetragonorhynchus mrakibensis*, and *Phacoiderhynchus antiatlasicus*; comments on the previous confusion of the latter with *Calvinaria undulata*, which is thought to belong to a different, new genus.

DAVIS et al. (1999): Illustration of crinoidal holdfasts on cymaclymeniids from "ca. 40 km S of Erfoud", but in fact from specimens of the Aguelmous Syncline.

BECKER et al. (1999): Summary of the Famennian ammonoid zonation of the southern Maïder.

KORN (1999a, 1999b): Middle/upper Famennian ammonoid succession of the eastern Anti-Atlas, with a first section log for the Madène el Mrakib, its ammonoid ranges, and the position of black shale units. Rich Sidi Ali, a section of unspecified location and stratigraphy in the southern Maïder, is the type locality of *Posttornoceras sapiens* [type species of *Maideroceras* BECKER, 2002], the Jebel Aguelmous is the type locality of *Posttornoceras weyeri* [now type species of *Ebbighausenites* KORN, BARTZSCH & WEYER, 2016a], and the Madène el Mrakib is the type locality of *Protoxyclymenia wendti*.

BECKER (2000): Review of wocklumeriid clymenids, with first records from the Fezzou region of *Parawocklumeria patens* and *Par. paprothae*, and the description of unusually small-sized representatives of *Wo. sphaeroides* subspecies [now *Wo. olivia*]; with the Fezzou region as the probable type area for the rare, purchased *Synwocklumeria mapesi* and *Kielcensia ingeniens*.

KEUPP (2000): Illustration of a *Sporadoceras* sp. [in fact a *Discoclymenia cucullata*], a *Discoclymenia* [an *Alpinites zigzag*], and of two *Prionoceras* from the Fezzou region.

BECKER et al. (2000): Middle to upper Famennian ammonoid succession of the Jebel Mrakib, evaluating its potential as a GSSP section for the base of a formal upper Famennian substage.
CORRADINI et al. (2001): First conodont data for the Mrakib, noting a strange bloom of coniform elements above the *Annulata* Event Beds.
BECKER (2002): Description of Posttornoceratidae from the southern Maïder, with the Madène el Mrakib as the type locality of *Alpinites schultzei*, Taourirt as the type locality of *Alp. zigzag*, and a re-assignment of *Posttornoceras sapiens* KORN, 1999b to the new sporadoceratid genus *Maideroceras*.
SPREY (2002): Illustration of a *Cymaclymenia striata* from Mrakib.
BECKER et al. (2002): Review of the Famennian ammonoid zonation of the eastern Anti-Atlas with many new records of taxa; with Mrakib as the type locality of *Afrolobites mrakibensis, Pricella canalifera,* and *Karaclymenia saharae*, and Rich Bou Kourazia as the type locality of *Praemeroceras dahmanii* and *Kourazoceras elhassanii*.
KORN & KLUG (2002): Illustration of various Famennian ammonoids from the Fezzou area, partly without specific provenience; with the Madène el Mrakib as the type locality of *Prolobites mrakibensis* [a junior synonym of *Afrolobites mrakibensis*] and the Jebel Aguelmous as the type locality of *Medioclymenia aguelmousensis*.
BECKER (2003): Review of Famennian ammonoid zones of the eastern Anti-Atlas, using the Mrakib section as an important example for successions around the *Annulata* Events.
WEBSTER et al. (2005): Refinement of the upper to uppermost Famennian litho- and ammonoid stratigraphy of the Aguelmous Syncline; Mrakib as the type locality of *Mrakibocrinus bockwinkeli*, Rich Bou Kourazia as the type locality of *Moroccocrinus ebbighauseni*, which were both attached to wood logs; description in open nomenclature of a new catillocrinid from the Jebel Mrakib.
BRICE et al. (2005): Description of a *Syringothyris* cf. *uralensis* from just below the main (lower) *Acutimitoceras-Gattendorfia* fauna at Bou Tlidat.
KAISER (2005) and KAISER et al. (2011): Description of two sections, Lambidia and Bou Tlidat, representing the western and eastern limbs of the Aguelmous Syncline, in a study on the Devonian/Carboniferous transition and Hangenberg Crisis of the eastern Anti-Atlas.
HÜBERS (2007): Empirical study concerning the relationships between whorl expansion rates and septal spacing, partly based on Mrakib and Fezzou region collections.
EBBIGHAUSEN & KORN (2007): Morphometric study of triangularly coiled wockumeriids and parawocklumeriids, including collections from the southern Maïder; with Bou Tlidat as the type locality of the micromorphic *Wo. oblivia* and Tizi Malilane near Fezzou as the type locality of the rare *Wo. boulmanensis*.
KORN et al. (2007): Review of Lower Carboniferous ammonoid stratigraphy of North Africa, with special reference to the *Gattendorfia-Eocanites, Gattendorfia-Kahlacanites,* and *Goniocyclus-Protocanites* assemblages of the Aguelmous Syncline.
EBBIGHAUSEN & BOCKWINKEL (2007): Monographic treatment of the lower/middle Tournaisian goniatite fauna of the Aguelmous Syncline: with Bou Tlidat as the type locality of *Acutimitoceras sarahae, Ac. endoserpens, Costimitoceras aitouamar,* and *Kornia citrus,* Tizi Ibaouâne as the type locality of *Ac. pentaconstrictum, Hasselbachia arca, Gattendorfia lhceni* [placed by BECKER in HAHN et al. 2012 in the related genus *Zadelsdorfia*], and *Gattendorfia gisae*, and with Rich el Mbidia as the type locality of *Globimitoceras rharrhizense* [which represents a new genus].
BRICE et al. (2007): Brief reference to the *Syringothyris* from just above the "Aguelmous Sandstone" at Bou Tlidat.
REMKE (2007), FISCHER (2010), and FISCHER & BECKER (2012): Palaeopathology of Famennian and lower Tournaisian ammonoids of the Tafilalt/Maïder, partly based on large collections from the Aguelmous Syncline.
DERYCKE et al. (2008): Description of shark and actinopterygian teeth and of an acanthodian scale from Mrakib.
GARCIA GARCIA (2008): Description of a new upper Famennian species of the gastropod *Straparollus*, mostly based on material from the Aguelmous Syncline.
DOPIERALSKA (2009): Use of Madène el Mrakib samples in the analysis of neodymium isotopes in order to reconstruct sea water circulation patterns.
NAWRATH (2009) and FISCHER (2013): Ontogenetic morphometry of Prionoceratidae from the eastern Anti-Atlas, including many specimens from the Aguelmous Syncline.
HARTENFELS & BECKER (2009a, 2009b): Development of the global Dasberg Crisis at the Jebel Mrakib, with its international correlation, sea-level changes, conodont and ammonoid data.
NAGEL-MYERS et al. (2009): Description of the asymmetric cryptodont bivalves *Loxopteria gibbosa, L. problematica*, and *L. meioklina* (type locality at Jebel Mrakib).

BECKER & HARTENFELS (2010): Brief reference to a possibly global trophic crisis as the cause for the poorly fossiliferous interval below the *Annulata* Events at Mrakib (and other Anti-Atlas sections).
HARTENFELS (2011): Detailed litho-, conodont-, and ammonoid stratigraphy as well as local sea-level changes at Mrakib, from just below the Lower *Annulata* Event to just above the global Dasberg Crisis level. Recognition of a *Caenodontus* bloom in the Wagnerbank Equivalents (lower part of the upper Famennian); type locality of *Clydagnathus tragelehni*, characteristic for the *Protoxyclymenia wendti* Bed near the top of Famennian IV.
KAISER et al. (2011): Sedimentary and faunal developments around the Devonian-Carboniferous boundary in the eastern Anti-Atlas.
HAHN et al. (2012): Monograph of the Lower Carboniferous trilobites of the SE Anti-Atlas, with a record of *Particeps* from the lower Tournaisian of Bou Tlidat, which is also the type locality of *Cyrtoproetus (Crassibole) acrops*; Tizi Ibaouane as the type locality of *Diacoryphe (Archaeocoryphe) maiderensis* and Tazoult as the type locality of *Dechenelloides tazoultensis*.
KEUPP (2012) and HOFFMANN & KEUPP (2015): Illustration of a *Prionoceras* with varices and of lower Famennian pathological specimens of *Cheiloceras undulosum* from the "Fezzou area".
GEESINK (2013): B.Sc. study on the peculiar trace fossil *Cruziana reticulata* from the lower Tournaisian of Tazoult.
KORN et al. (2013): Review of the Famennian and Tournaisian of the Aguelmous Syncline, with an emphasis on the problems of surface collections.
SCHWERMANN (2014): New study on shark teeth from the eastern Anti-Atlas, with new records of *Denea* cf. *fournieri* and *Protacrodus serra* for the Mrakib.
KLEIN & KORN (2014): Morphometric study on Anti-Atlas Cymaclymeniidae; with the Madène el Mrakib as the type locality of *Procymaclymenia ebbighauseni* and *Cymaclymenia lambidia* [close to the German *Cyma. involvens*], and the Aguelmous as the type locality of *Cyma. aulax* [a close relative of *Cyma. sudetica*] and *Cyma. carnata*; complete list of cymaclymeniid occurrences at all localities of the southern Maïder and Tafilalt.
KORN et al. (2014): New section log for the upper Famennian at Madène el Mrakib, with ranges of *Prionoceras* species as the base for a new regional biozonation; type locality of *Pr. lentis, Pr. subtum*, and *Pr. mrakibense*.
KLUG et al. (2015a): Re-illustration of a *Wocklumeria sphaeroides* (specimen of EBBIGHAUSEN & KORN 2007) from Bou Tlidat, as an example for mature septal crowding.
KLUG et al. (2015b) and FREY et al. (2015, 2018): The southern Maïder as an important Fossillagerstätte, with the correlation between occurrences of different fossil groups, and the reconstruction of palaeoecological and local palaeodiversity trends.
MONNET et al. (2015): Illustration of an Eifelian *Pinacites eminens* from the Jebel El Mrakib, of a Famennian *Prionoceras lamellosum* from the main section, and of an unidentified orthoceratid from Lambidia.
KORN et al. (2015a): Description of Anti-Atlas *Mimimitoceras*, with an account of faunas from various localities of the Aguelmous Syncline; Madène el Mrakib as the type locality of *Mim. carnatum, Mim. comtum,* and *Mim. alidrisii,* Taourirt as the type locality of *Mim. endocuboide* and *Mim. taourirtense*, and Lambidia as the type locality of *Mim. ibnishaqi*.
KORN et al. (2015b): Description of upper [not middle; see BECKER et al. 2012 for proposed Famennian substage definitions] Famennian sporadoceratids from the eastern Anti-Atlas, with the Madène el Mrakib as the type locality of *Ungusporadoceras unguiforme* [which is, however, a praeglyphioceratid, see discussion in HARTENFELS & BECKER 2016].
HARTENFELS & BECKER (2016): Update on the faunas and conodont biofacies around the global *Annulata* Events at Mrakib; type locality of *Gundolficeras australe* and *Posttornoceras ascendens* (= *Post*. aff. *contiguum* in BECKER 1995).
KORN et al. (2016b): First part of description of upper Famennian tornoceratids from the eastern Anti-Atlas, with Taourirt as the type locality of *Post. janae* and Fezzou as the type locality of *Discoclymenia atlantea* [very close to the European *Disco. cucullata*, better only a subspecies].
KORN et al. (2016c): Second part of description of upper [not middle, as said in the title] Famennian tornoceratids from the eastern Anti-Atlas, with the Madène el Mrakib as the type locality of *Gund. vescum* [a close relative of *Gund. delepinei*] and *Post. elegantulum* [objective junior synonym of *Post. ascendens* HARTENFELS & BECKER, 2016].
KLUG et al. (2016): Description of ammonoids uniquely preserved with their jaws in situ from the topmost Devonian Hangenberg Black Shale of two sections at Madene El Mrakib and from Lambidia.
BAIDDER et al. (2016): Aerial photo based structural geology of the Maïder, showing a few minor oblique faults cutting through the Famennian E of Fezzou.
KAISER et al. (2016): Illustration of the thick D/C boundary siliciclastics at Bou Tlidat.

FREY et al. (2017) and KLUG et al. (2017): Discovery of skeletal remains of a phoebodontid shark.
KORN & BOCKWINKEL (2017): Revision of the Anti-Atlas gonioclymeniids, with the Madène el Mrakib as the type locality of *Gonio. spiniger* [holotype = *Gonio. hoevelensis* in BECKER et al. 2002] and Rich Bou Kourazia as the type locality of *Gonio. ebbighauseni* and *Gonio. inornata*.

4. Lithostratigraphy

The lithostratigraphic subdivision of the Maïder Devonian goes back to the work of the famous H. HOLLARD. However, many of his units were never formalized by detailed lithological descriptions or by the selection of type sections. In the first stratigraphic chart by HOLLARD (1963), a succession of thick Famennian shales and shales with sideritic or calcareous nodules was shown to be overlain by the "Grès de l´Aguelmous n. ou Fezzou". The name was kept on the geological map (1 : 200 000) Todrha-Ma´der (DESTOMBES et al. 1988) and the chart was re-illustrated in HOLLARD (1981a). A second set of charts in the same volume (HOLLARD 1981b), however, used the name Fezzou Formation for strata assigned to the Upper Devonian VI (now uppermost Famennian). No explanation for this nomenclatorical change was offerred. Below, the lower to upper Famennian succession was placed in a new Ibaouane Formation, the ca. lower half of the Tournaisian in a new Rharriz Formation.
The research progress of the last decades enables refinements of this subdivision. The base of the **Ibaouane Formation** is here defined to coincide with the Frasnian-Famennian boundary, which is best exposed at Rich Bou Kourazia (e.g. BECKER et al. 2002, fig. 3, base of Bed A). The new, ca. 32 m thick **Rich Bou Kourazia Member**, named after its type locality, consist of three subunits. At the base, there are black, partly nodular to concretionary goniatite limestones (ca. 4 m, Beds A_1 to A_3), followed by goniatites shales with hematitic/goethitic faunas that alternate with thin, black goniatites limestones (Beds B to F, ca. 6.7 m). Above a thin hematite crust, there are poorly fossiliferous green shales and siltstones (Beds G to H_2, ca. 31.5 m). The new **Lahfira Member** (Fig. 5), named after the small village E of the Rich Bou Kourazia type section (Fig. 3), begins with a re-onset of hematitic/goethitic goniatite shales at the base of the middle Famennian (UD II-G; Fig. 12). In the Rich Bou Kourazia type section, the member is ca. 60 m thick (WEBSTER et al. 2005, fig. 3, Beds I to N). It consists of alternating green shales, marls and thin limestones that are partly very rich in goniatites. The new **Mrakib Member**, with the type-section at Madène el Mrakib, begins at the base of the Lower *Annulata* Shale (BECKER et al. 2002, base of Bed N_{1c}; Figs. 6, 12). Upwards, it encompasses all of Upper Devonian IV, up to a red marker crust at the top of Bed R (Fig. 21). It is ca. 25 m thick and consist of alternating black, red to orange anoxic shales (Figs. 12, 13), ammonoid-rich, partly cyclic, green shales, and thin ammonoid limestones or black goniatite nodule levels. The new **Jebel el Krabis Member**, named after the Famennian hill just opposite (to the N) of the last hill at the Madène el Mrakrib type section, begins with the Dasberg Crisis Interval (HARTENFELS 2011; base of Bed S_1, basal UD V-A). It is marked by the return of fossiliferous ammonoid shales after a fossil-poor interval at the top of UD IV. Upwards, goethite, siderite, and calcareous nodules become very common (Fig. 23), especially at the top (*Wocklumeria* Beds; e.g. KORN 1999; KAISER et al. 2011). The thickness is ca. 47 m at Madène el Mrakib but varies along the Aguelmous Syncline. The ca. 2 m thick regional Hangenberg Black Shale equivalents are here re-named as **Bou Tlidat Member**, after its type locality at the NNW of the Aguelmous Syncline (e.g. KAISER et al. 2011, fig. 4; BOCKWINKEL & EBBIGHAUSEN 2007, fig. 3). It is a pyrite-rich, only locally fossiliferous (KLUG et al. 2016) black shale that weathers reddish, white, or orange.
Adopting the original terminology of HOLLARD (1963), the name **Aguelmous Formation** is re-established for the thick siliciclastic wedge of the regressive middle Hangenberg Crisis Interval (sensu KAISER et al. 2016; Fig. 19). It is up to 200 m thick and consists of a (pro)deltaic succession with shales, siltstones, and massive sandstones/quartzites. We propose to restrict the term **Fezzou Formation** of HOLLARD (1981b) to the overlying, fossiliferous, lower Tournaisian goniatite shales intercalated by siderite-rich sandstones, which carry pelagic or mixed neritic-pelagic faunas. In this way, the formation term has been used in the northern Maïder (BECKER et al. 2013). There a tongue of the Aguelmous Formation is developed as thin-bedded, brachiopod-rich siltstones and fine sandstones within the Lalla Mimouna Formation. All over the Maïder, the re-defined Fezzou Formation grades upwards into the deeply weathering shales with decalcified concretions of the Rharrhiz Formation. It represents the middle/upper Tournaisian and is a close equivalent of the Oued Znaïgui Formation of the southern Tafilalt (see KAISER et al. 2011).

Fig. 5: The middle Famennian Lahfira Member of the succession at the northern end of Madène el Mrakib, with the basal upper Famennian Wagnerbank Equivalents (basal Mrakib Member) in the cliff in the distance.

Fig. 6: The two red *Annulata* Event beds at the northern end of Madène el Mrakib, separated by the nodular *Annulata* Intralimestone in the middle (Bed 10b = N_{1b}), and with the nodular ledge of Bed 9b (=N_{1a}) at the base of the gully, and the three Wagnerbank Equivalents (lower Mrakib Member, Beds N_{2a-d} = 11c-13b) at the top.

Fig. 7: Details of the three layers of fossiliferous marly, nodular to more solid limestone that make up the regional, regressive (in relation to the anoxic Upper *Annulata* Shale) Wagnerbank Equivalents (lower Mrakib Member, Beds 11a-13b = N_{2a-e}).

Fig. 8: The jellowish-brownish weathering top of the Wagnerbank Equivalents, showing mass occurrences of squashed platyclymeniids (lower Mrakib Member, top of Bed 13b = N_{2e}).

Fig. 9: A strongly compressed (ww/wh = 0.74 at 44 mm diameter) *Platyclymenia (Pl.)* cf. *levata* (rather involute form with uw/dm = 0.40) from the upper Wagnerbank Equivalent (lower Mrakib Member, Bed 13b = N_{2e}, upper UD IV-A).

Fig. 10: Mass occurrence of weathered goniatites (mostly *Prionoceras*) in the lower part of Bed 14e (= O_{2a}; lower Mrakib Member).

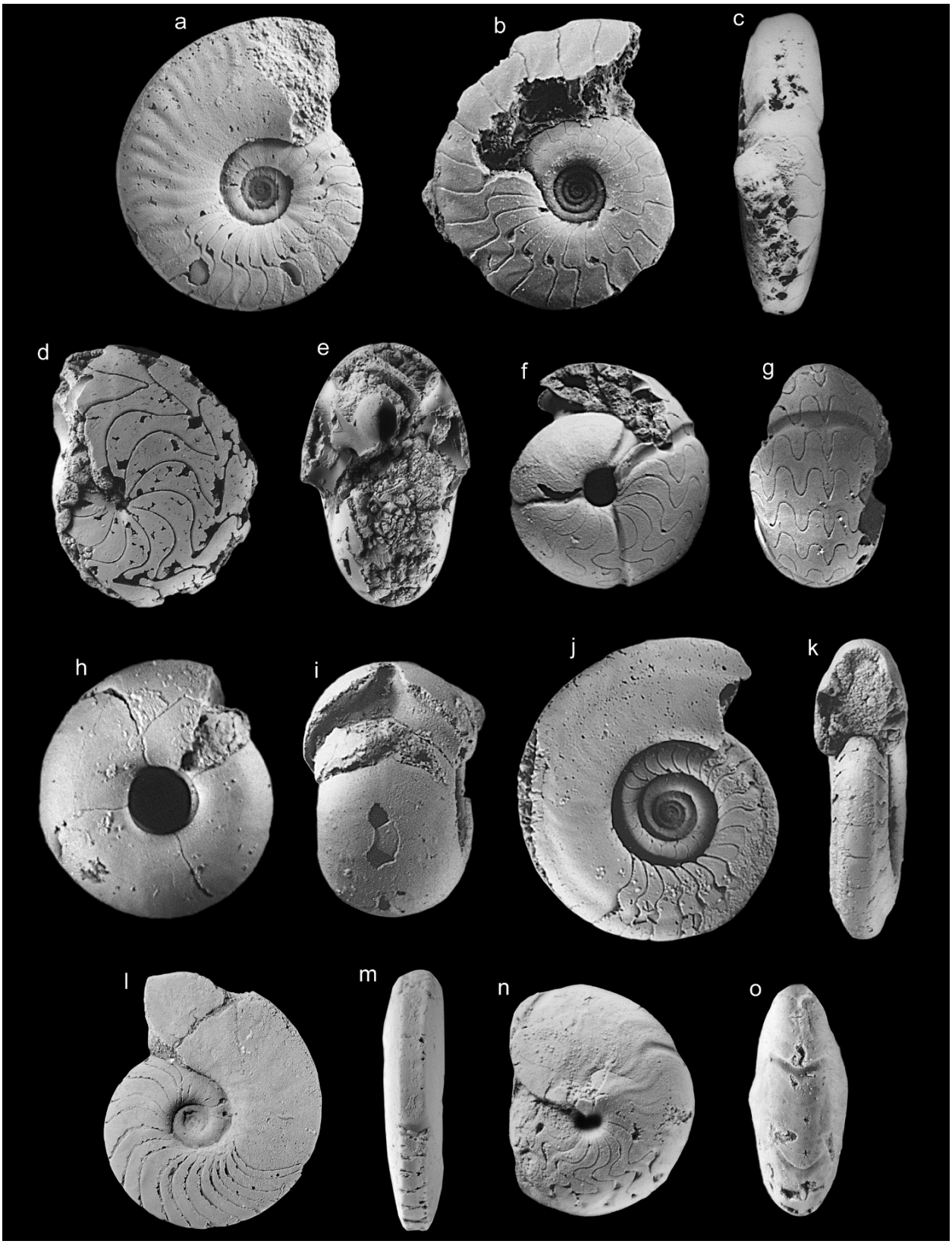

Fig. 11: Typical middle Famennian ammonoids from Madène el Mrakib. **a.** *Planitornoceras euryomphalum* ssp. 1 with lamellose ribbing, MB.C. 3550, BECKER et al. (2002, pl. 4, fig. 1), Bed H_1, x 3. **b-c.** *Plani. euryomphalum* ssp. 2 with ventral varices, Be 1342, BECKER (1995, pl. 1, figs. 9-10), loose, x 3.8. **d-e.** *Erfoudites spiriferus*, spiral ornament not preserved, MB.C. 3545, BECKER et al. (2002, pl. 2, figs. 1-2), Bed H_1, x 2. **f-g.** *Enkebergoceras varicatum*, juvenile showing the open umbilicus, MB.C.3547, BECKER et al. (2002, pl. 2, figs. 7-8), Bed K, x 3.6. **h-i.** *Afrolobites mrakibense*, holotype showing the extremely widely spaced septa, MB.C.3510, BECKER et al. (2002, pl. 1, figs. 3-4), Bed H_2, x 6.7. **j-l.** *Sulcoclymenia sulcata*, MB.C.3523, BECKER et al. (2002, pl. 4, figs. 2-3), Beds J/K, x 3.8. **l-m.** *Pricella canalifera*, holotype, MB.C.3505, BECKER et al. (2002, pl. 6, figs. 5-6), Bed H_1, x 2.9. **n-o.** *Maideroceras sapiens*, MB.C.3449.1, BECKER (2002, pl. 3, figs. 3-4), Bed H_2, x 3.

5. Madène el Mrakib / Jebel Mrakib

The repeatedly and intensively studied section of the Jebel Mrakib or Madène el Mrakib lies ca. 60 km SE of Msissi, at the northern end of an elongated, ca. SW-NE running hill, 25 km SE of Fezzou, at GPS N 30°45,4´, W 4°42,8´. The Aferdou el Mrakib mudmound, which is surrounded by trilobite trenches, can be seen to the SE at ca. 2 km in the distance. There are partial section logs in KORN (1999), BECKER et al. (2002), WEBSTER et al. (2005), HARTENFELS (2011), and KORN et al. (2014). BECKER & HOUSE (2000) provided a complete overview for the middle to uppermost Famennian.

5.1. Rich Bou Kourazia Member

The Frasnian/Famennian boundary and lower Famennian Rich Bou Kourazia Member can be sampled at the locality of WENDT & BELKA (1991: x = 566, y = 414.5), following the piste to the SSW. A loose sample by RTB included brownish, goethitic *Armatites beatus, Compactoceras (Com.) undulosum undulosum*, and *Com. (Com.) verneuilii*. It was strongly contaminated by partly abraded, black, hematitic goniatites from the higher UD III/IV. FREY et al. (2018) emphasized a "phyllocarid layer" as an important level for exceptionally preserved vertebrate remains; it was assigned to the *Maeneceras* Zone (UD II-G).

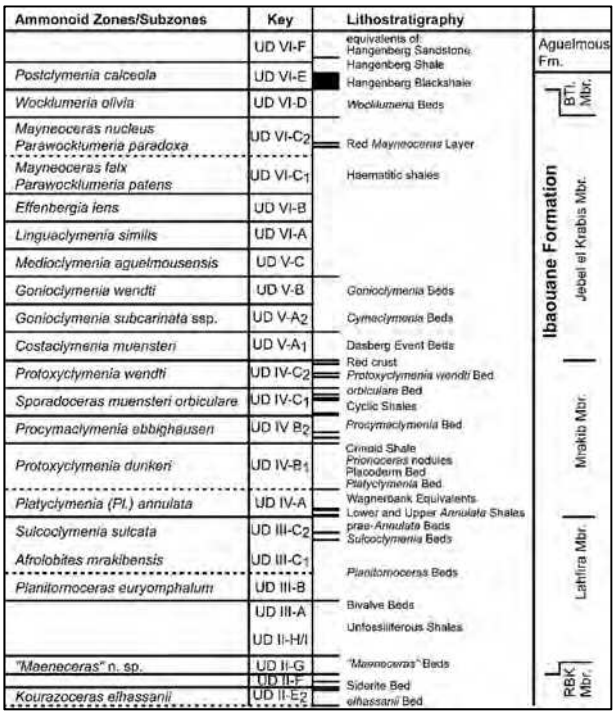

Fig. 12: Overview of the top lower to uppermost Famennian ammonoid zonation, lithological marker units, and formations/members of the Aguelmous Syncline area (updated from WEBSTER et al. 2005, fig. 4).

5.2. Lahfira Member

The base of this member has been fixed at Rich Bou Kourazia, where goniatites of the upper part of UD II can be collected at several levels (BECKER et al. 2002). However, there is currently no record of any index ammonoid genera of UD II-H to III-A from all of the Maïder. The corresponding interval is fossil-poor and was probably oligotrophic.

At Madène el Mrakib, the higher Lahfira Member is well exposed in the lower slope of the main section near the northern end of the hills (Figs. 1, 5). Characteristic are thick, unfossiliferous green, silty shales at the base. The detailed section log of BECKER et al. (2000, 2002) commenced with the first shales with macrofauna:

Bivalve Beds (Fig. 12)**:** Beds A to D_3 consist of a ca. 7.5 m thick alternation of green shales and thin, nodular or platy limestones at the top of sedimentary cycles. The macrofauna is dominated by bivalves that are typival for pelagic settings, such as *Guerichia*, *Buchiola*, and *Myalina*. Single goniatites were probably derived from overlying units.

***Planitornoceras* Beds** (Fig. 12)**:** Beds D_4 to J_1, ca. 25 m thick, mostly greenish, silty shales with thin, nodular, pink, red, or brownish, sideritic limestones at the top, and a rich goethitic fauna that indicates dysoxic conditions. The fauna from the lower part (Beds D_4 to G) falls in the regional *Plani. euryomphalum* Zone and Subzone (UD III-B). Characteristic are:

orthocones indet.
Lobobactrites paucesinuatus
Planitornoceras euryomphalum (three regional variants or subspecies with or without varices or with strong ribbing of inner whorls; Figs. 11a-c)
Gundolficeras n. sp. (two different forms)
Enkebergoceras varicatum (with variants; Figs. 11f-g)
Maideroceras sapiens (Figs. 11n-o)
Erfoudites spiriferus (Figs. 11d-e)
Falcitornoceras aff. *falcatum*
abundant bivalves (*Loxopteria, Buchiola, Guerichia*, nuculoids, *Myalina*)
bellerophontids and other gastropods
rhynchonellids

The UD III-B fauna is mixed with subordinate UD IV specimens derived from above, a general problem of faunas collected from the weathered surface. Based on several rare taxa that are typical for UD III-C (the classical "do IIIß"), such as the oldest clymeniids, Beds H_1 to J_1 have been assigned to a regional *Afrolobites mrakibense* Subzone. Re-sampling proved that index genera, such as *Pricella*, can be re-collected (Figs. 11l-m). Typical are:

Afrolobites mrakibensis (Figs. 11h-I, very rare)
Planitornoceras euryomphalum (all variants)
Gundolficeras n. sp.
Posttornoceras ascendens
Enkebergoceras varicatum
Maideroceras sapiens
Erfoudites spiriferus
Pricella canalifera (Figs. 11l-m, very rare)
Lobobactrites sp.
various bivalves (*Buchiola, Guerichia, Leptodesma, Loxopteria*)
bellerophontids and other gastropods
Pugnaria cf. *plana*
crinoid ossicles

***Sulcoclymenia* Beds:** Beds J_2 to L_1, ca. 3 m thick, greenish, silty shales with a pink siderite/hematite crust at the top of Bed J_2, a platy bed with numerous squashed *Sulcoclymenia* on the upper surface of Bed J_{3b}, and a brown, sideritic marker limestone at the top of Bed K. Based on its index species (Figs. 11j-k), this succession falls in the *S. sulcata* Zone (UD III-C_2), which also occurs widely in the Tafilalt (BECKER et al. 2002; HARTENFELS 2011; HARTENFELS & BECKER 2016). It enables an easy correlation with the higher part of the traditional German *Prolobites delphinus* Zone (e.g. SCHINDEWOLF 1923; KORN & ZIEGLER 2002). All common species of the *Plani. euryomphalum* Zone are still present but the rare *Afrolobites* and *Pricella* have not been found.

Pre-*Annulata* Beds: BECKER et al. (2000) and BECKER & HARTENFELS (2010) emphasized that the ca. 3-3.5 m of greenish shales with some thin, intercalated limestones (Figs. 12-14, Beds 2a to $10a_1$ of HARTENFELS 2011 = L_2 to N_{1b}) below the Lower *Annulata* Shale are suddenly rather poor in macrofauna. There are just a few squashed *Enkebergoceras, Erfoudites,* or indeterminate sporadoceratids and rhynchonellids left. Conodont faunas are also sparse, with a few *Scaphignathus velifer velifer* and *Palmatolepis perlobata schindewolfi* in Beds 2b and 6b, respectively (HARTENFELS 2011). They indicate the regionally expanded *Sc. velifer velifer* Zone and prove that *Scaphignathus* was not a shallow-water genus.

Since there is a very similar trend at the top of UD III in pelagic settings of many other, partly far distant regions, such as the Rhenish Massif or even the Canning Basin of NW Australia, the gradual disappearance and eventual extinction of the "IIIß Fauna" may have been caused by a climate-controlled global trophic crisis. Both at the generic and species level, there was a severe faunal overturn of ammonoids in the eastern Anti-Atlas. Among the Maïder Basin taxa, only *Erfoudites, Gundolficeras,* and *Posttornoceras* survived, but partly with a change of species.

5.3. Mrakib Member

The lower part of the member, around the two global *Annulata* Shales and three-fold Wagnerbank Equivalents, has been refined by BECKER et al. (2002), WEBSTER et al. (2005), and HARTENFELS (2011), the thicker upper part mostly by KORN et al. (2014). The succession of distinctive beds and faunas can be summarized as follows:

Lower *Annulata* Black Shale: A 70-80 cm thick, hematite-rich "redshale" (based on pyrite-weathering) with a very pecular, small-sized goniatite fauna (Figs. 6, 12-14; Bed $10a_2$ = N_{1c} = ca. Beds N_{b4} to N_{d1} of KORN et al. 2014). Its peculiar preservation, characterized by dense incrustations of hematized pyrite framboids, washed in or encrusted guerichiids and juvenile gasteropods, and the red-orange weathering, prevents a confusion with goethitic specimens derived from above. The faunal composition is also distinctive (HARTENFELS & BECKER 2016) and includes several index forms of the basal UD IV (*Platyclymenia (Pl.) annulata* Zone):

Gundolficeras australe (Figs. 15a-b; 37 % of ammonoids)
Erfoudites zizensis (Figs. 15c-d, 25 %)
Protactoclymenia aff. *subcostata* (Figs. 15-e-f, 20 %)
Stenoclymenia rectangula (fragmentary, 8 %)
Platyclymenia (Pl.) annulata richteri
Platyclymenia (Pl.) subnautilina subnautilina
Platyclymenia (Pl.) latecostata
Pl. (Trigonoclymenia) protacta (all platyclymeniids = 8 %)
Prionoceras sp. indet. (only 2 %)
Falcitornoceras sp. [single specimen of WEBSTER et al. 2005]
Lobobactrites cf. *paucesinuatus*
very common bivalves (*Guerichia, Leptodesma, Buchiola*)
common juvenile naticopsids

The re-onset of a diverse fauna dominated by juveniles and the absence of brachiopods suggest eutrophic but strongly hypoxic sedimentation.

Intra-*Annulata* Beds: Two less pyrite-rich shales sandwich a thin *Annulata* Intra-Limestone (ca. 70-80 cm, Figs. 6, 12-14, Beds $10a_3$ to 11a = N_{1e} to lower part of N_{1f} = N_{1d1} to N_{1f1} in KORN et al. 2014). The latter is characteristed by a rather special, low-diversity and low-abundance conodont fauna with a high percentage of *Alternognathus*. Such a curious conodont biofacies is not known from other levels (HARTENFELS & BECKER 2016). There are hardly any ammonoids (one poor protactoclymeniid).

Upper *Annulata* Shale: The lithology of the ca. 60-80 cm thick upper "redshale" (Figs. 6, 12-14; Bed 11b = upper Bed N_{1f} = Bed N_{1f2}) closely resembles the lower "redshale" but, by contrast, there is hardly any macrofauna, only rare, squashed *Prionoceras* sp. and *Pl. (Platyclymenia)* sp. This suggests that the environment was completely anoxic.

Wagnerbank Equivalents: Beds 11c to 13b (= N_{2a} to N_{2e} = N_{1f3} to N_{2e} in KORN et al. 2014; Figs. 6-7, 12-14) consist of three highly fossiliferous marl-limestone cycles that can be correlated with the Wagnerbank of Thuringia, which also directly overlies the *Annulata* Shales (e.g. PFEIFFER 1954; HARTENFELS 2011). Again, there is a strange conodont fauna. This time it belongs to a unique *Caenodontus* Biofacies (CORRADINI et al. 2001; HARTENFELS 2011, HARTENFELS & BECKER 2016). *Caenodontus* is one of the few remaining, and normally very rare coniform conodonts of the post Kellwasser Crisis time. The rich ammonoid assemblage contains some very large-sized platyclymeniids (*ibnsinai* Group), which may enable a (local) subdivision of the *Pl. (Pl.) annulata* Zone (UD VI-A). KORN et al. (2014) introduced a regional *Pr. vetum* Zone (nom. corr.). But its index species occurs elsewhere (El Gara, Tafilalt) already in marly equivalents of the Lower *Annulata* Shale (HARTENFELS & BECKER 2016). Fauna:

"Prionoceras" vetum
Prionoceras frechi ssp.
Erfoudites sp.
Ungusporadoceras unguiforme
Platyclymenia (Pl.) cf. *levata* (Fig. 9) [det. *pseudoflexuosa* in BECKER et al. 2000]
Platyclymenia (Pl.) subnautilina ssp.
Platyclymenia (Pl.) quiringi
Platyclymenia (Pl.) annulata rotundata (sensu HARTENFELS & BECKER 2016)
Platyclymenia (Pl.) ibnsinai Group [det. cf. *intracostata* in BECKER et al. 2000]
Loxopteria, Guerichia, and other bivalves
rhynchonellids
proetid remains in cephalopod body chambers

Erfoudites is not common at this level but clearly present, contrary to the much higher entry considered by KORN et al. (2014, p. 172). The top surface (of Bed 13b = N_{2e}) is covered by masses of squashed, goethized *Platyclymenia* (Fig. 8). They indicate a return to strongly hypoxic conditions.

***Prionoceras* Beds:** The 35-50 cm thick shale of Bed 14a-c (= O_{1a}; Figs. 12-14) is characterized by a mass occurrence of goethitic *Prionoceras*, platyclymeniids, and other ammonoids. A terrace or gentle slope above the ledge of the Wagnerbank Equivalents enables good collecting but it is often difficult to separate float specimens from above (see KORN et al. 2013, 2014). Bed 14d (= O_{1b}) is a level of concretions that formed around numerous large but disarticulated, titanichthyid placoderm skeletons. This gave the name **Placoderm Bed** in WEBSTER et al. (2005). Two specimens were transported in 2000 to the Museum für Naturkunde, Berlin, but have not been identified or published. Rich *Prionoceras* faunas continue in the ca. 3.15 to 3.30 m thick Bed 14e (= O_{2a}, Fig. 13; subdivided in KORN et al. 2014, Fig. 14). There are monospecific assemblages from flat, black goniatite limestone concretions (*Prionoceras* Limestone of BECKER et al. 2000). The faunal list for Bed O includes:

Ungusporadoceras unguiforme
"Prionoceras" lentis (Figs. 15q-r)
Prionoceras divisum lamellosum
Prionoceras takhbtitense
Erfoudites ssp.
Platyclymenia (Pl.) levata
Platyclymenia (Pl.) limata
Platyclymenia (Pl.) quiringi
Platyclymenia (Pl.) annulata rotundata [compare KORN 1999, pl. 5, fig. 2]
Platyclymenia (Pl.) div. sp.
Pl. (Trigonoclymenia) protacta
Carinoclymenia beuelense (Figs. 15o-p)
Karaclymenia saharae
Protactoclymenia div. sp.
Protoxyclymenia dunkeri
Protoxyclymenia cf. *wendti* [possibly from above]
breviconic and longi-orthoconic cephalopods
Aulacella sp.
rhynchonellids
chondrichthyan fin spines

Taxa that do not occur in the higher faunas are assumed to be from Bed O. This includes the rare *Prot. dunkeri* (BECKER et al. 2000, HARTENFELS 2011; HARTENFELS & BECKER 2016), which date at least the middle/higher part as UD IV-B_1 (lower *Protoxyclymenia* Genozone). Unfortunately, protoxyclymeniids are generally rare in the eastern Anti-Atlas, which makes it difficult to pinpoint their entry in all studied sections. KORN et al. (2014) introduced a regional *Pr. lamellosum* Zone but since its index form (better a subspecies of *Pr. divisum*) enters in the Tafilalt earlier, at the base of UD IV-A (HARTENFELS & BECKER 2016), the zone is a synonym of the *"Pr." vetum* Zone.

The upper part of Bed O yielded a single colonial coral (*Pseudoendophyllum*, det. D. WEYER). It is of highest phylogenetic significance since it bridges the long gap between topmost Frasnian and uppermost Famennian ("Strunian") colonial Rugosa.

***Platyclymenia* Bed:** The thin (6 cm) limestone at the top of Bed O (Bed 14f = O_{2b}) can be traced around the northern end of the Jebel Mrakib hills because its upper surface is covered by squashed, goethitic platyclymeniids. Its conodont faunas are similar as in the Wagnerbank Equivalents, including the occurrence of *Caenodontus*. In the absence of the marker species *Polygnathus styriacus* and *Pa. perlobata postera* in the Anti-Atlas, it is not possible to correlate this level with the "standard conodont zonation" (HARTENFELS 2011). A dark limestone nodule of KORN (1999: Sample E) and KORN et al. 2014 (Bed O_{2m}) yielded dominant *Pr. divisum lamellosum*.

"Crinoid Shale": Bed 15a-e (= P_1, Fig. 13; subdivided in KORN et al. 2014, Fig. 14) is a ca. 6-7 m thick package of green shale, which became famous for its thin lenses of crinoid debris. A large

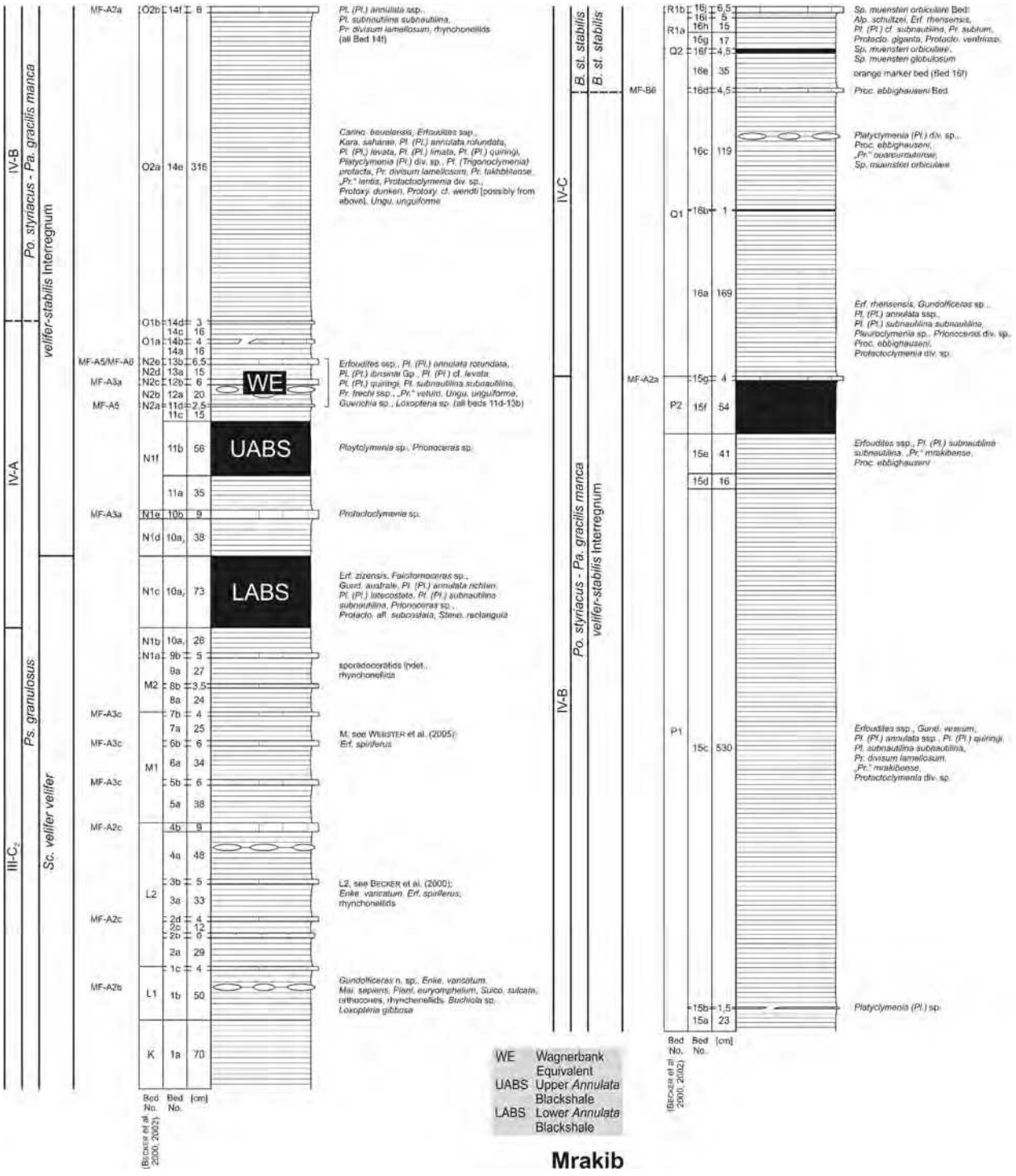

Fig. 13: Litho- and biostratigraphy of the Mrakib Member, with the position of ammonoid faunas; LABS and UABS = Lower and Upper *Annulata* Blackshales, WE = equivalents of the German (Thuringian) Wagnerbank (updated from HARTENFELS 2011).

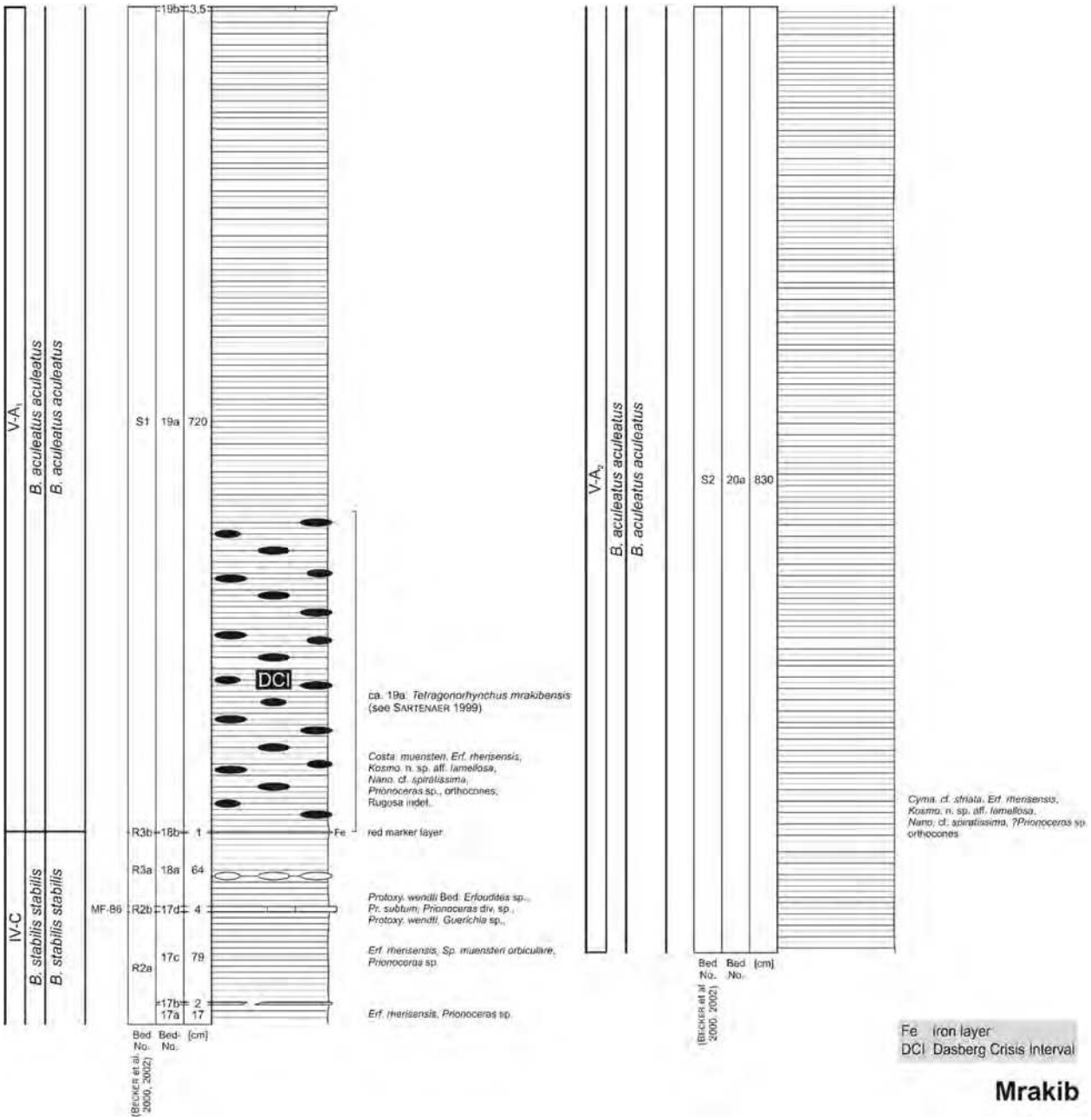

Fig. 13 (continuation): Litho- and biostratigraphy of the Mrakib Member, with the position of ammonoid faunas; LABS and UABS = Lower and Upper *Annulata* Blackshales, WE = equivalents of the German (Thuringian) Wagnerbank (updated from HARTENFELS 2011).

wood log from the upper part was attached by filigrane, complete *Mrakibocrinus bockwinkeli* WEBSTER, BECKER & MAPLES, 2005. A single micrite concretion with *Procymaclymenia ebbighauseni* (= *Proc. pudica* in BECKER et al. 2000, 2002; a closely related taxon), the index species of UD IV-B_2, was collected near the top (HARTENFELS & BECKER 2016). KORN et al. (2014) used the entry of *Pr. mrakibense* in middle to upper parts of Bed P to define a regional *Pr. mrakibense* Zone. Loose faunas from Bed P_1 include various species of *Platyclymenia, Protactoclymenia, Erfoudites, Gundolficeras* (e.g. *G. vescum* KORN, EBBIGHAUSEN & BOCKWINKEL, 2016c), and *Posttornoceras*. Placoderm plates and rhynchonellids occur, too. Float specimens from above are difficult to recognize in the surface collections.

Third Blackshale: Bed P_2 (= 15f) is a 54-60 cm thick, red to orange weathering black shale that KORN (1999) originally regarded as the Upper *Annulata* Shale. KORN et al. (2014, 2015b) noted that *Pr. mrakibense* and *Erf. rherisensis* are typical at this level.

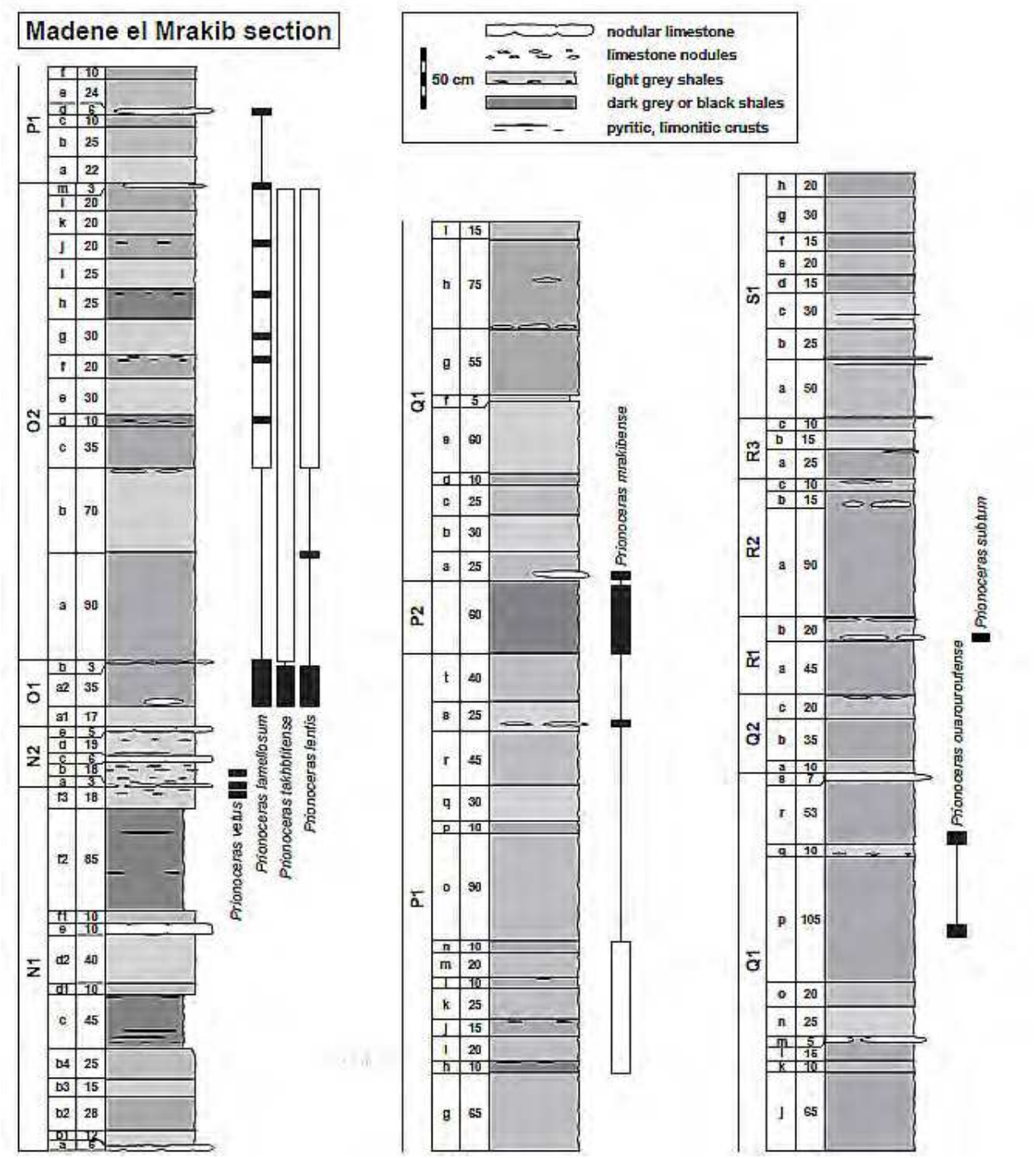

Fig. 14: Lithological log for the Lahfira Member (UD IV) at Madène el Mrakib by KORN et al. (2014, fig. 3), showing levels of excavated prionoceratid faunas.

Cyclic Shales: The up to 6 m thick greenish-grey shales of Bed Q_1 (= 16a-e; subdivision in KORN et al. 2014) are more solid and cyclic than the shales below. Therefore, they form a small cliff. Goethitic ammonoids are very abundant:

Gundolficeras sp.
Prionoceras ouarouroutense
Prionoceras div. sp.
Erfoudites rherisensis
Sporadoceras muensteri orbiculare (from the upper part)
Platyclymenia (Pl.) annulata ssp.
Platyclymenia (Pl.) div. sp.
Pleuroclymenia sp. (from the lower part, first reliable record for the Anti-Atlas)
Protoxyclymenia cf. *wendti* (incomplete, from the upper part)
Protactoclymenia div. sp.
Procymaclymenia ebbighauseni (common from the base to the top)
rhynchonellids

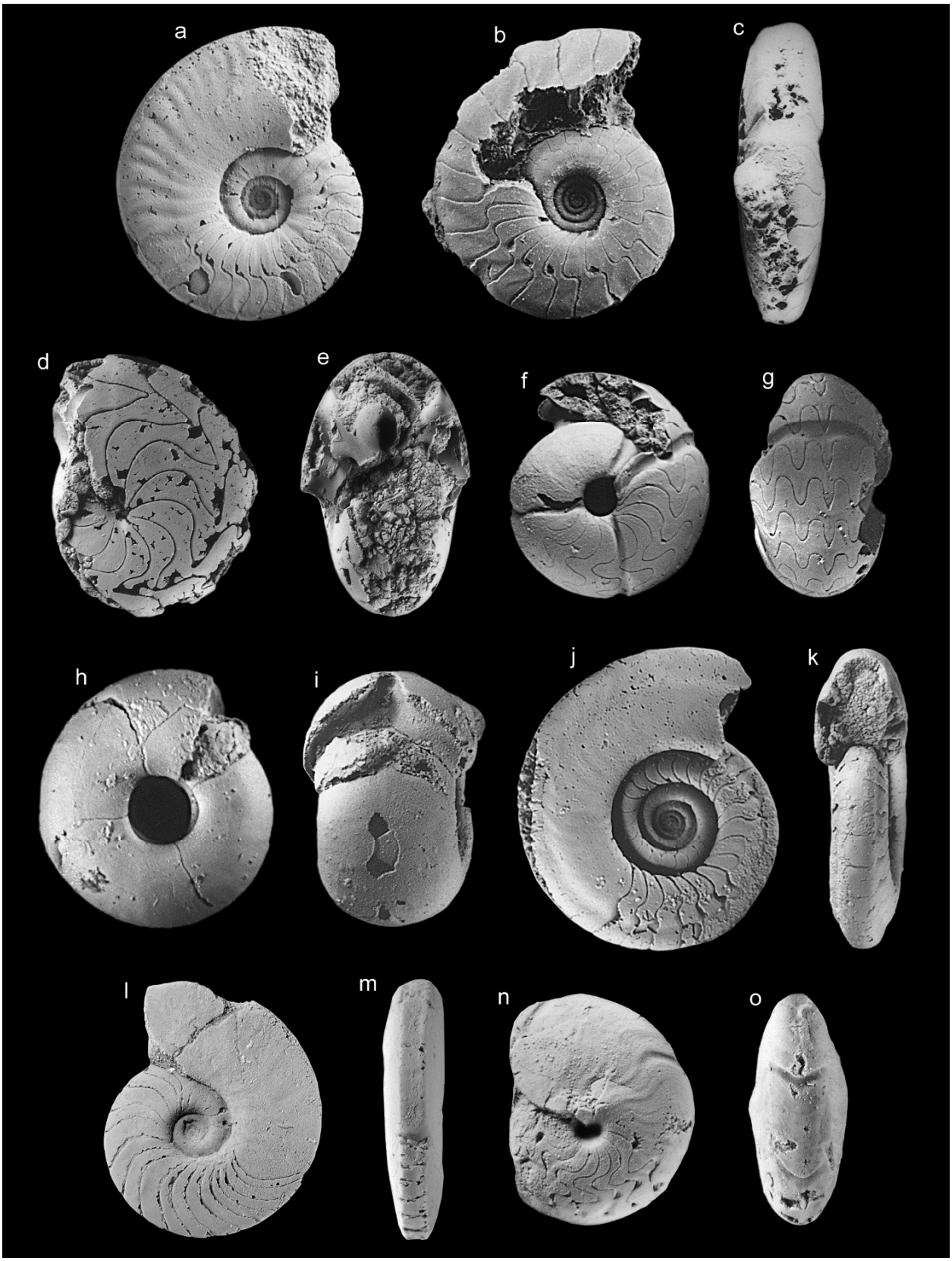

Fig. 15: Typical ammonoids from the Mrakib Member (UD IV) of Madène el Mrakib. **a-b.** *Gundolficeras australe*, holotype B6.C-47.211 (HARTENFELS & BECKER 2016, figs 16.4a-b), Lower *Annulata* Shale, x 4. **c-d.** *Erfoudites zizensis*, B6.C-47.212 (HARTENFELS & BECKER 2016, figs. 16.3a-b), Lower *Annulata* Shale, x 4. **e-f.** *Protactoclymenia* aff. *subcostata*, B6.C-47.218 (HARTENFELS & BECKER 2016, figs. 17.1a-b), Lower *Annulata* Shale, x 3. **g-h.** *Procymaclymenia ebbighauseni*, MB.C.3524 (BECKER et al. 2002, pl. 4, figs. 4-5), Bed O, loose (probably derived from Bed Q), x 2. **i-j.** *Protoxyclymenia* cf. *wendti*, B6.7-47.225 (HARTENFELS & BECKER 2016, figs. 17.3a-b), Bed O, loose (possibly derived from Bed Q), x 3. **k-l.** *"Prionoceras" lentis,* Bed O, loose, x 2. **m-n.** *Posttornoceras ascendens*, holotype, Eb-C2 = MB.C.3461 (BECKER 1995, pl. 3, figs. 1-2, = holotype of *Post. elegantulum* KORN, BOCKWINKEL & EBBIGHAUSEN, 2016c), loose, x 2.5. **o-p.** *Carinoclymenia beuelensis*, Bed O, loose, x 2.

The benthic fauna is sparse apart from some gastropods. Platyclymeniids become gradually rare upsection. Based on small-sized, goethitic *Sp. muensteri orbiculare*, the base of UD IV-C lies in Bed Q_{1p} of KORN et al. (2014). KORN et al. (2014) introduced a corresponding *Pr. ouarouroutense* Zone for the prionoceratid succession.

***Procymaclymenia* Bed**: Bed 16d (= Q_{1s} in KORN et al. 2014; Fig. 14) is a yellowish-reddish weathering, dark-grey, detrital marker bed with a mass occurrence of *Proc. ebbighauseni.* Its conodonts fall in the regional *Bispathodus stabilis stabilis* or international (Lower) *Pa. gracilis expansa* Zone (HARTENFELS 2011). Both index species are present. Ca. 35 cm higher, there is the thin, again orange weathering **Forth Blackshale** (Bed 16f = Q_2; Fig. 18).

***Orbiculare* Beds:** 40-45 cm of green shales (Bed R_{1a} = 16g-i) are followed by two levels of micritic, hard, and fossiliferous limestone nodules (Bed 16j _ R_{1b}, main *orbiculare* Bed, Samples I/J of KORN 1999), which contain isolated, often large, goniatites, clymeniids, and nautiloids:

Alpinites schultzei
Sporadoceras muensteri orbiculare (Fig. 16)
Sporadoceras muensteri globulosum
Erfoudites rherisensis
Prionoceras subtum
Platyclymenia (Pl.) cf. *subnautilina*
Protactoclymenia ventriosa (= *Cyrtoclymenia* sp. of KORN 1999, pl. 3, fig. 1)
Protactoclymenia giganta (Fig. 19)
cf. *Onyxites* sp. (Fig. 17)

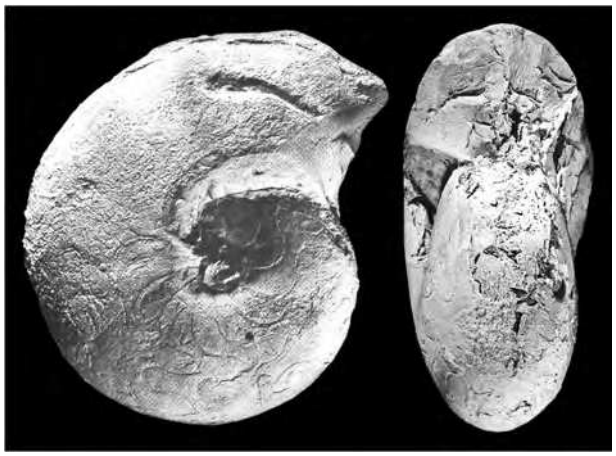

Fig. 16: Subadult *Sporadoceras muensteri orbiculare* from the nodular *orbiculare* Bed, upper Mrakib Member (Bed 16j = R_{1b}, *Sp. muensteri orbiculare* Zone, UD IV-C_1; BECKER et al. 2002, pl. 4, figs. 8-9); max. diameter = 93 mm.

It is not clear whether favorable ecological or taphonomic conditions are the reason that several species of unrelated ammonoid lineages reach large size in this unit. Trophic conditions may have been optimal for a brief period. KORN et al. (2014) introduced a regional *Pr. subtum* Zone that begins with Bed R_{1b}. The overlying Beds 17a-c (= R_{2a}, ca. 1 m thick) carries only squashed *Sp. muensteri orbiculare, Prionoceras*, and *Erfoudites*.

Fig. 17: Large, endogastric discosorid nautiloid (cf. *Onyxites* n. sp.), adapical and lateral views, loose from the upper Famennian, probably from the main *orbiculare* Bed (based on the style of preservation), max. adoral diameter = 10 cm, length of fragment = 10.3 cm.

***Prot. wendti* Bed:** Bed R_{2b} (= 17d) is a lenticular, thin limestone with mass occurrences of ammonoids, especially of the name-giving *Prot. wendti* (Figs. 12, 14, 20). Associated are *Pr. subtum*, a thin prionoceratid, *Erfoudites,* and common bivalves (*Guerichia*). The conodont assemblage is

Fig. 18: The orange-weathering thin black shale (Bed 16f = Q_2) in the upper *Procymaclymenia ebbighauseni* Zone (UD IV-B_2).

Fig. 19: Fully septate fragment (at 9.3 cm whorl height) of the giant *Protactoclymenia giganta* from the *orbiculare* Bed (Bed 16j = R_{1b}, UD IV-C).

Fig. 20: The *Protoxyclymenia wendti* Bed (Bed 17b = R_{2b},) high in the Mrakib Member (upper UD IV-C).

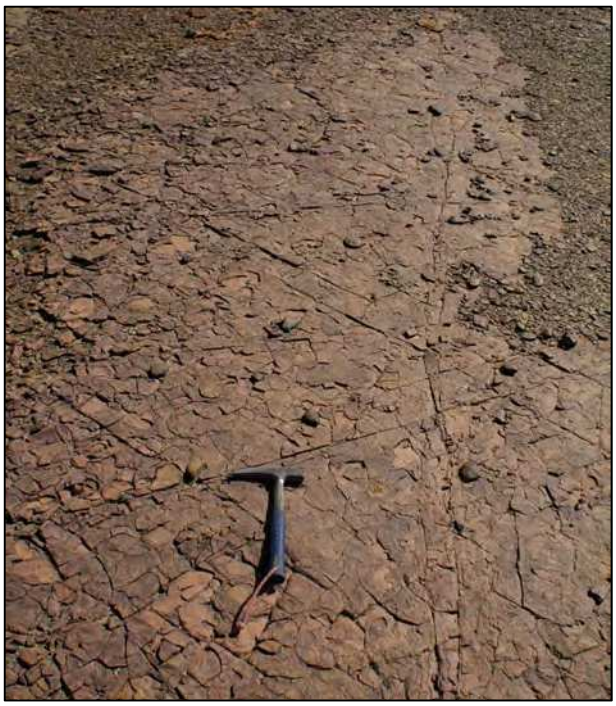

Fig. 21: The poorly fossiliferous, sideritic Red Crust (Bed 18b = R_{3b}) at the top of the Mrakib Member (top of UD IV).

Fig. 22: Higher part of the succession at the northern end of Madène el Mrakib (Jebel el Krabis Member, UD V/VI), with Bed S_2 in the lower part and the massive quartzites/sandstones of the Aguelmous Formation forming the top cliff.

Fig. 23: Typical Jebel el Krabis Member, rich in fossiliferous siderite/limestone nodules forming occasional solid beds (basal part of Bed U; UD V-A_2).

distinctive, with a dominance of simple spathognathodids (*Branmehla*, three subspecies of *B. stabilis*) and clydagnathids (type-level of *Cl. tragelehni* HARTENFELS, 2011). The disappearance of *Caenodontus* and several palmatolepids underlines a marked change of conodont biofacies. The overlying shales (Bed R_{3a} = 18a) are very poor in macrofauna (squashed sporadoceratids).

Red Crust: The thick iron crust of Bed 18b (= R_{3b}; Fig. 21) marks probably a sedimentary discontinuity or starvation surface, when there was a high influx of diluted iron, but without an associated discharge of fine siliciclastics from the arid hinterland. The strong decline of cephalopod content at the end of UD IV and the extinction of some of its marker ammonoids (platyclymeniids, certain prionoceratids and protactoclymeniids) indicates another phase of strong oligotrophy, as at the top of UD III (in the pre-*Annulata* Beds).

5.4. Jebel el Krabis Member

Dasberg Crisis Interval: The ca. 7 m thick Beds 19a-b (= S_1) are characterized by the return of a small-sized, poorly preserved hematitic fauna. It suggests a re-newed episode of poorly oxygenated and eutrophic conditions, as the local expression of the global Dasberg Crisis (e.g. HARTENFELS & BECKER 2009, HARTENFELS 2011). This interpretation is supported by several index ammonoids for the basal Dasbergian (UD V-A_1), which are, however, rare.

Erfoudites rherisensis (by far dominant)
Prionoceras sp.
Costaclymenia muensteri
Nanoclymenia cf. *spiratissima* [= N. Gen. aff. *Platyclymenia teicherti* in BECKER et al. 2000]
Kosmoclymenia n. sp. aff. *lamellosa*

The top of Bed S_1 is marked by a thin limestone with a reddish surface. The ca. 8-9 m subsequent Bed S_2 (= 20a; Fig. 22) carries a poor fauna including dominant *Erf. rherisensis*, a poorly preserved *Cymaclymenia striata* ssp. (HARTENFELS 2011, pl. 71, fig. 1), *Nanoclymenia,* and early kosmoclymeniids (*K.* n. sp. aff. *lamellosa*).

***Cymaclymenia* Beds:** Bed T (= 20b-g), ca. 7.5 to 8 m of green or thinly laminated, dark-grey shales with fossiliferous nodules or nodular limestones in the upper part. Cymaclymeniids are abundant, which gave the name, but there are also common *Erfoudites* and kosmoclymeniids. The preliminary faunal account, indicating UD V-A_2, is:

"Gundolficeras" fezzouense
Gundolficeras cf. *escoti*
Erfoudites div. sp.
Cymaclymenia striata formosa
Kosmoclymenia lamellosa
Mimimitoceras sp.

***Gonioclymenia* Beds:** Beds U/V comprise a ca. 7 m thick similar succession as Bed T (Fig. 23). It differs mostly in the presence of gonioclymeniids. Ammonoids are variably preserved as nodules with strong diagenetic subsolution or are either squashed or fully preserved goethitic specimens. The fauna is highly divers:

"Gundolficeras" fezzouense (compare Figs. 25i-j)
Ebbighausenites weyeri [= *Posttornoceras posthumum* in BECKER 2002] (compare Figs. 25e-f)
Discoclymenia cucullata atlantea (compare Figs. 25a-b)
Alpinites zigzag (compare Figs. 25c-d)
"Rectimitoceras" pompeckji Group
"Mimimitoceras" carnatum [including *Rectimitoceras lineare* of BECKER et al. 2000]
"Mimimitoceras" comtum
Erfoudites rherisensis
Cyrtoclymenia angustiseptata Group
Cymaclymenia striata formosa
Cymaclymenia costellata [compare a paratype of "*Cyma. subvexa*" KLEIN & KORN, 2014, fig. 13B]
Gonioclymenia subcarinata ali
Gonioclymenia spiniger [included in the closely related *Gonio. hoevelensis* in BECKER et al. 2002; Figs. 18g-h]
Gonioclymenia wendti [the regional close relative of *Gonio. speciose*]
Kosmoclymenia lamellosa
Muessenbiaergia div. sp. (Fig. 24)
rhynchonellids
bundled *Cladochonus* colonies growing on ammonoids
Guerichia sp.
Palaeotaxodont bivalves
rare proetid trilobites
chondrichthyan fin spines

Fig. 24: *Muessenbiaergia* aff. *parundulata*, more evolute than *Muess. sublaevis*, tabulate venter without flares but with fine growth lines, with an epizoan holdfast on the body chamber, loose from the higher part of the Jebel El Krabis Member at Madène el Mrakib, 67 mm diameter.

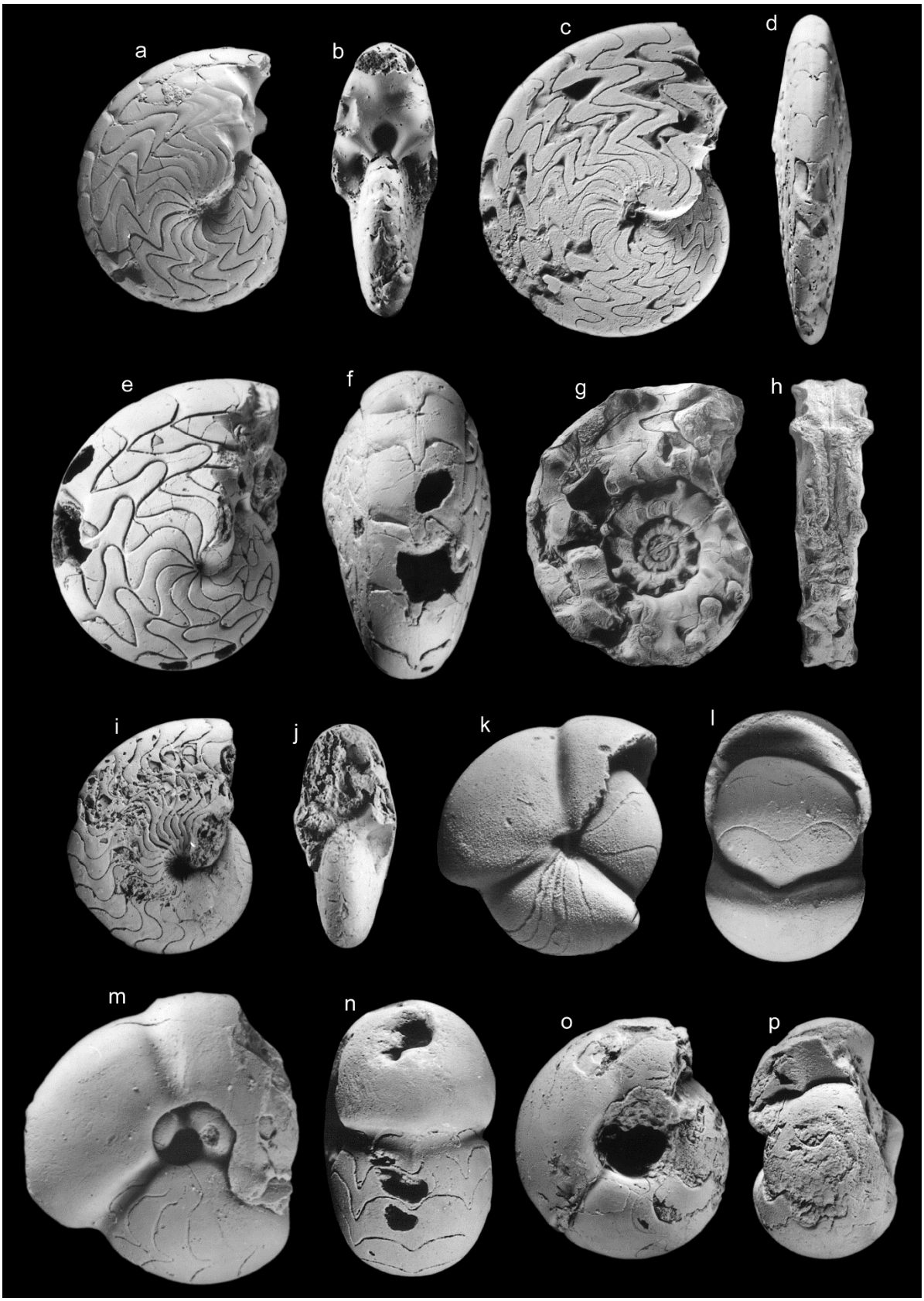

Fig. 25: Typical ammonoids of Jebel el Krasis Member (UD V/VI). **a-b.** *Discoclymenia cucullata atlantea*, Ü164/10, FU Berlin (BECKER 1995, pl. 3, figs. 5-6), loose, x 1.2. **c-d.** *Alpinites zigzag*, MB.C.3431 (original of BECKER 2002), loose, x 2. **e-f.** *Ebbighausenites weyeri*, MB.C.3446 (BECKER 2002: pl. 2, figs. 9-10), loose, x 1. **g-h.** *Gonioclymenia spiniger*, holotype, MBC.3555 (BECKER et al. 2002, pl. 6, figs. 1-2), Mrakib, Beds U/V, loose, x 1.5. **i-j.** *"Gundolficeras" fezzouense*, holotype, Be 1331 = MB.C.1692 (BECKER 1995, pl. 2, figs. 10-11), purchased, x 1.5. **k-l.** *Parawocklumeria paprothae*, MB.C.3061 (BECKER 2000, pl. 4, figs. 7-8), loose, x 5. **m-n.** *Kielcensia ingeniens*, holotype, MB.C. 2705 (BECKER 2000, pl. 4, figs. 9-10), purchased, x 3. **o-p.** *Wocklumeria denckmanni*, loose, x 5.

Fig. 26: Flatened ammonoids from Hangenberg Black Equivalents (Bou Tlidat Member) of Madène el Mrakib; scale bar = 10 mm (reproduced from KLUG et al. 2016, fig. 3). **A, E.** Tornoceratid with biconvex ornament and high whorl expansion. **B-D**. *Mimimitoceras* sp., showing growth lines, low whorl expansion, jaw remains and organic coating between the jaw and the last septum (C). **F, H.** *Acutimitoceras* sp., vertically and laterally embedded specimens showing biconvex growth lines and strong varices (H). **G, I-J.** *Postclymenia calceola* showing sutures and an in-situ anaptychi, and the protoconch (I-J).

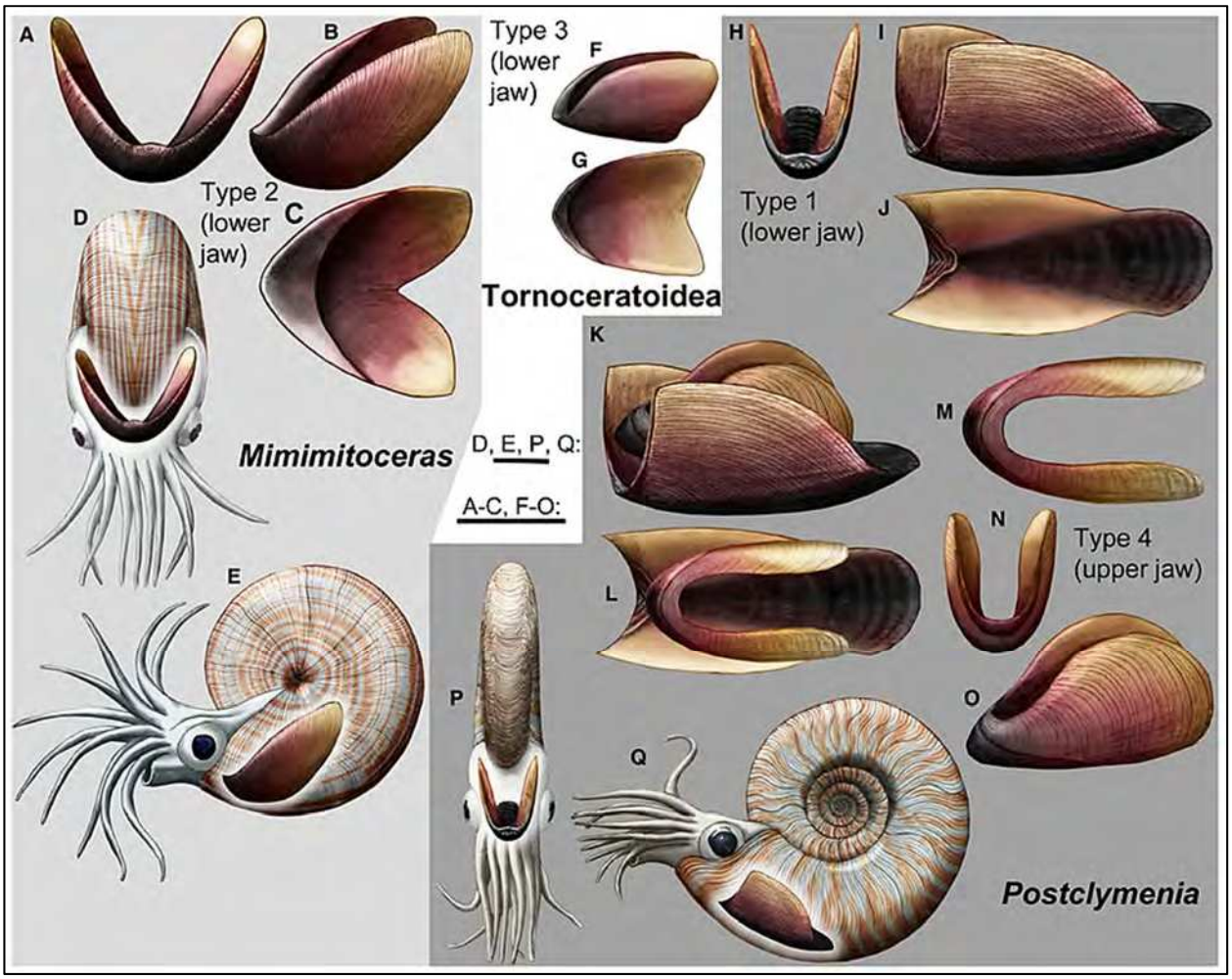

Fig. 27: Reconstruction of jaws and the living animal in three different ammonoid groups (Tornoceratoidea, Prionoceratoidea: *Mimimitoceras*, Clymeniina: *Postclymenia*) from the topmost Famennian Hangenberg Shale Equivalents (Bou Tlidat Member; reproduced from KLUG et al. 2016, fig. 8).

The presence of *Gonio. wendti, Gonio. spiniger*, and *Muessenbiaergia* is typical for UD V-B (BECKER et al. 2002). KORN et al. (2015a) introduced a corresponding regional *Mimimitoceras comtum/carnatum* Zone.

Haematitic Shales: The fossiliferous green shales with abundant hematitic ammonoids of the top Dasbergian (UD V-C) to lower/middle Wocklumian (UD VI-A/C), known, e.g., from Lambidia (BECKER et al. 2002; KAISER et al. 2011) and Bou Tlidat (see below), are widely covered at Madène el Mrakib by debris from the higher Aguelmous Formation. The main part of Bed W of BECKER et al. (2000) is also less fossiliferous than the equivalent strata of the more northern sections. KORN et al. (2015a) described from this interval *"Mimimitoceras" alidrisii*.

***Wocklumeria* Beds:** The upper part of Bed W contains, as everywhere along the Aguelmous Syncline, a fauna preserved in sideritic nodules (KAISER et al. 2011). Most characteristic are paedomorphic, small-sized wocklumeriids (BECKER 2000), assigned to *Wo. oblivia* by EBBIGHAUSEN & KORN (2007). But there are also subordinate normal-sized relatives (*Wo. sphaeroides*, see KORN 1999, pl. 3, fig. 3). The *Wocklumeria* fauna defines UD VI-D (e.g. BECKER 2000; BECKER et al. 2002). Other uppermost Famennian ammonoids from Madène el Mrakib include *Cymaclymenia involvens lambidia, Cyma. carnata, Lissoclymenia wocklumeri,* and *Kenseyoceras nucleus.*

5.5. Bou Tlidat Member

At Madèdene el Mrakib, the member is ca. 2 m thick and consists of organic-rich black shale (claystone), which was excavated in two lateral localities for its globally unique fauna of ammonoids with in-situ jaws, accompanied by orthocones; bryozoans, acanthodian teeth, plant remains; and abundant guerichiid bivalves (KLUG et al. 2016). The cephalopods preserve fine details of ornament and their organic (chitinous) aptychi (Fig. 26), even upper jaws, which are virtually unknown elsewhere

in the Devonian. Specimens became available after the removal of weathered surface material and occur on several bedding surfaces in the upper part of the member. Especially important is the fact that the jaw apparatus could be reconstructed for representatives of several unrelated taxonomic groups, such as the Tornoceratina (Tornoceratoidea and two genera of the Prionoceratoidea), and Clymeniina (Cyrtoclymenioidea) (Fig. 27). The overall similarity between all four types, with the only other previous Famennian finding (Frye & Feldmann 1991), and with the more common jaws in Frasnian Gephuroceratina, suggest that principally similar types of the buccal apparatus were present in the last common ancestor, possibly going back to the oldest Ammonoidea.
The Madène el Mrakib ammonoid assemblage from the *Postclymenia* Zone (UD VI-E) shows that the last tornoceratids and mimimitoceratids survived very briefly into the initial anoxic interval of the Hangenberg Crisis. This agrees with some other cases of short-termed survival (BECKER et al. 2016, tab. 2) and suggests a more staged extinction pattern than recognized previously.

Fig. 28: Overview of the ridge formed by quartzitic Hangenberg Sandstone equivalents in the Aguelmous Formation at Bou Tlidat (see from the NW), with the deeply weathered shales of the Ibaouane Formation to the N (right).

6. Bou Tlidat/Tizi Ibaouane

The NW Aguelmous Syncline, from Bou Tlidat to Tizi Ibaouane (Fig. 3; EBBIGHAUSEN & BOCKWINKEL 2007, fig. 1), is the best Anti-Atlas area to study both the Hangenberg Crisis Interval (KAISER 2005; KAISER et al. 2011) and faunas of the complete lower Tournaisian. The uppermost Famennian is exposed at Bou Tlidat (GPS: N 30°59,261´, W 4°51,821´). It ranges from the pyritic/goethitic shales of the Jebel el Krabis Member through the Aguelmous Formation. A section log for the main part of the pre-Hangenberg uppermost Famennian (UD VI-B/C) has not yet been published. The very rich fauna contains (det. RTB in FISCHER 2010):

Gundolficeras div. sp.
"Gundolficeras" fezzouense
Discoclymenia cucullata atlantea
Sporadoceras muensteri orbiculare
Mimimitoceras div. sp.
Effenbergia lens
Effenbergia falx
Effenbergia minutula
Kenseyoceras nucleus
Cymaclymenia costellata
Cymaclymenia striata ssp.
Cymaclymenia aulax
Muessenbiaergia sublaevis
Linguaclymenia similis
Linguaclymenia phillipsi
Parawocklumeria paradoxa
Synwocklumeria mapesi
Kalloclymenia subarmata
orthoconic cephalopods
Aulacella sp.
rhynchonellids
various bellerophontids
Straparollus n. sp.
Naticopsis sp.
other gastropods
nuculids
Leptodesma sp.
other bivalves
solitary rugose corals
Rabienops sp.
wood remains

Additional *Kielcensia ingeniens* (Figs. 25m-n) and *Parawocklumeria paprothae* (Figs. 25k-l) are known from loose specimens of the Fezzou region (BECKER 2000; EBBIGHAUSERN & KORN 2007). The faunal composition is typical for a deep, pelagic facies, with a restricted benthos adapted to low bottom oxygenation and a muddy substrate. Above a peculiar red shale, the top of the member (Bed -14 of KAISER 2005; Bed E of EBBIGHAUSEN & KORN 2007, fig. 3; ca. 9.5 m) is a green silty shale unit with abundant siderite nodules. This is the type level and locality of the paedomorphic *Wocklumeria oblivia* but slightly larger *Wo. denckmanni* occur, too (e.g. EBBIGHAUSEN & KORN 2007, fig. 13o; compare Figs. 25o-p). Both marker species of UD VI-D are accompanied by *Mimimitoceras*, *Cyma. involvens lambidia,* more compressed *Cyma. striata* ssp., the orthid *Aulacella*, and the last phacopids.
The originally black, multi-coloured weathering shales of the ca. 2 m thick Bou Tlidat Member (Bed -13 of KAISER 2005 = Bed C of EBBIGHAUSEN & KORN 2007) did not (yet) yield any fauna. This may reflect fully anoxic to euxinic conditions.
The Aguelmous Formation begins with a thick package (20-27 m) of olive-green, silty shales (lower slope in Fig. 28; Bed -12 = Bed B). These form a regional equivalent of the German greenish

Hangenberg Shale (lower part of Middle Crisis Interval, BECKER et al. 2016). KAISER et al. (2011) noted a very poorly preserved, questionable cymaclymeniid from its upper part. This record is based on a corroded, compressed and convolute ammonoid mould without sutures or ornament. The subsequent, almost 190 m thick alternation of siltstones, fine sandstones, and quartzitic marker beds is poor in shelly macrofauna but partly rich in trace fossils. There is a shallowing upwards trend until the thick, ridge-forming sandstones/quartzites of Bed 3 (ca. 5 m; Fig. 28). These contain a neritic shelly fauna (brachiopods, bivalves) and shallow-water arthropod tracks (*Diplichnites*). The top of the ca. 40 m thick filling-up/highstand interval may correlate with the German Hangenberg Sandstone (see review in KAISER et al. 2016). The higher part of the Aguelmous Formation, exposed on the inner slope (Fig. 28), is composed of monotonous turbiditic sandstones alternating with siltstones and shales (Beds 4 to X11 of KAISER 2005 and KAISER et al. 2011). They record an overall deepening trend but with several parasequences, due to the interplay of episodically increased subsidence, phases of eustatic rise, and sediment infilling. Starting ca. 135 m above the base of the formation, there is a poorly fossiliferous, shale-dominated interval with variably turbiditic or non-turbiditic sandstone interbeds (Beds X10 to X3a). Current ripples indicate a clastic discharge from the SE/SSE and the return to a distal prodeltaic environment. The Devonian-Carboniferous boundary of its current GSSP definition has tentatively been placed in the upper part, which contains a still unstudied brachiopod fauna in Bed RTB 8 (Fig. 30).

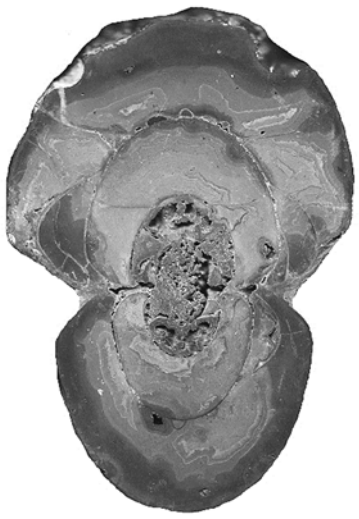

Fig. 29: Polished cross-section of *Acutimitoceras (Stockumites)* n. sp. aff. *kleinerae*, Bou Tlidat; Faunule 1, base of Bed RTB 10, ca. 53 mm diameter, ww/wh = 1.25 and ww/dm = 0.69; whorl expansion rate near 1.9 from 16 mm dm on, when ww/dm is lower than at maturity (< 0.65).

The base of the re-defined Fezzou Formation is marked by the sudden re-onset of shales with pelagic fauna (Fig. 30). The base of Bed RTB 10 (= X3a of KAISER 2005, lower part of Bed 2 of EBBIGHAUSEN & BOCKWINKEL 2007) yielded a level with reddish siderite nodules and a mixed neritic-pelagic Faunule 1. It consists of the spiriferid *Syringothyris* (BRICE et al. 2005), a wide-spread genus in the basal Tournaisian, the rather involute *Acutimitoceras (Stockumites)* n. sp. aff. *kleinerae*, characterized by an ontogenetic rise of ww/dm rations (Fig. 29), and fragmentary *Acutimitoceras (Stockumites)* sp. indet.

Bed RTb 10b (= X3a of KAISER 2005) contains the very abundant and diverse Fauna 2 described by EBBIGHAUSEN & BOCKWINKEL (2007, upper part of their Bed 2; Figs. 30-31). Good collecting is possible at Bou Tlidat (GPS: N 30°58,973´, W 4°51,234´) and, laterally to the NE, at Tizi Ibaouane (GPS N 31°00,482´, W 4°49,261´). Some taxonomic updates of the fauna will be required in future. For example, *"Costimitoceras" aitouamar* shows ventrolateral furrows (Figs. 35c-d) but no evidence for the characteristic net ornament that defines the genus. There are also a few additional forms, for example rather evolute and thick variants of *Acut. (St.) sarahae.* Associated is an important benthic fauna consisting of rare blastoids, crinoid stem pieces, *Aulacella*, rhynchonellids, oxyconic and well-rounded bellerophontids, pleurotomariids, other gastropods, nuculoids, other bivalves, rare hyolithids, conulariids, solitary rugose corals, and longi-orthoconic cephalopods. Based on the association of *Gattendorfia* aff. *crassa* (with more evolute early whorls than in the locally more common *Gatt. jacquelinae*), and *Kazakhstania evoluta*, this first *Gattendorfia-Eocanites* Assemblage of KORN et al. (2007), the regional *Gatt. jacquelinae* Zone of BECKER (in HAHN et al. 2012), can be roughly correlated with the German *Gatt. crassa* Zone sensu VÖHRINGER (1960). The absence of the normally characteristic Pseudarietitinae is most likely a palaeobiogeographic distinction (BECKER in HAHN et al. 2012, p. 39), not an indication of different age, as suggested by BOCKWINKEL & EBBIGHAUSEN (2006).

Bed RTB 11 (X3c of KAISER 2005) bears on its underside *Cruziana* tracks. This regional marker sandstone is much better developed at Tazoult (see below). Bed RTB 12 (= X2 of KAISER 2005) yielded only a few loose goniatites but pleurotomariids, bellerophontids, and *Aulacella* are proportionally more common than in the typical Fauna 2. Fauna 3 was collected loose from Bed RTB 17 (Fig. 29; =

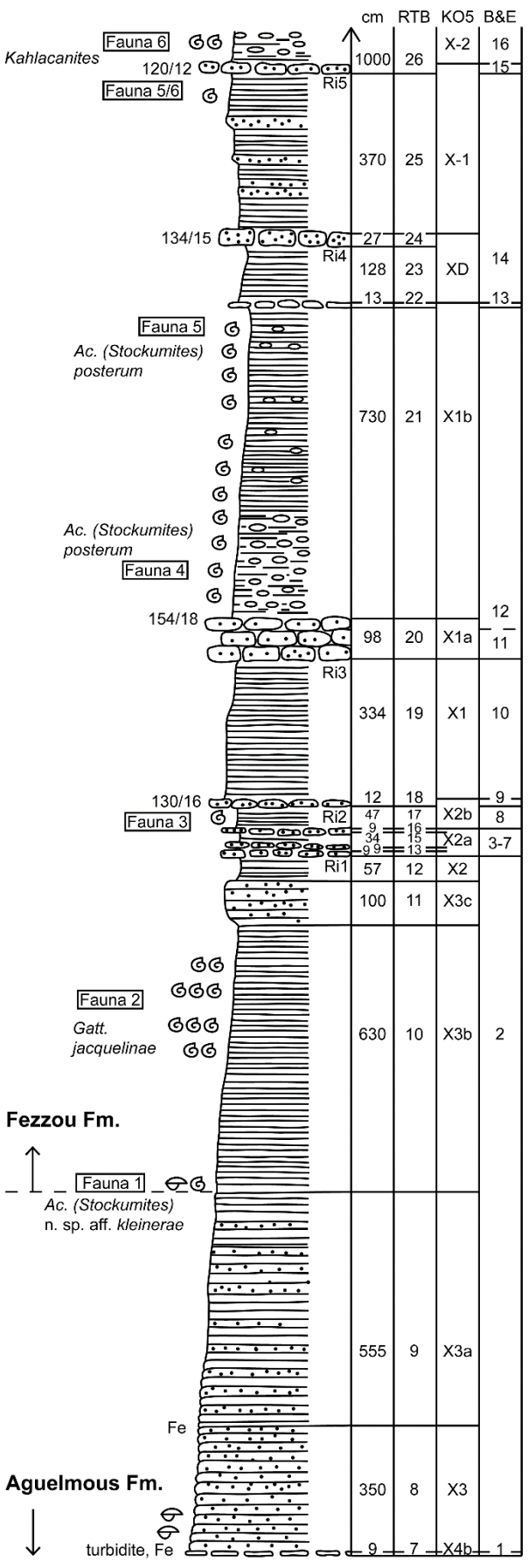

Fig. 30: New section log for the pelagic lower/middle Tournisian Fezzou Formation at Bou Tlidat, with the position of the main ammonoid levels.

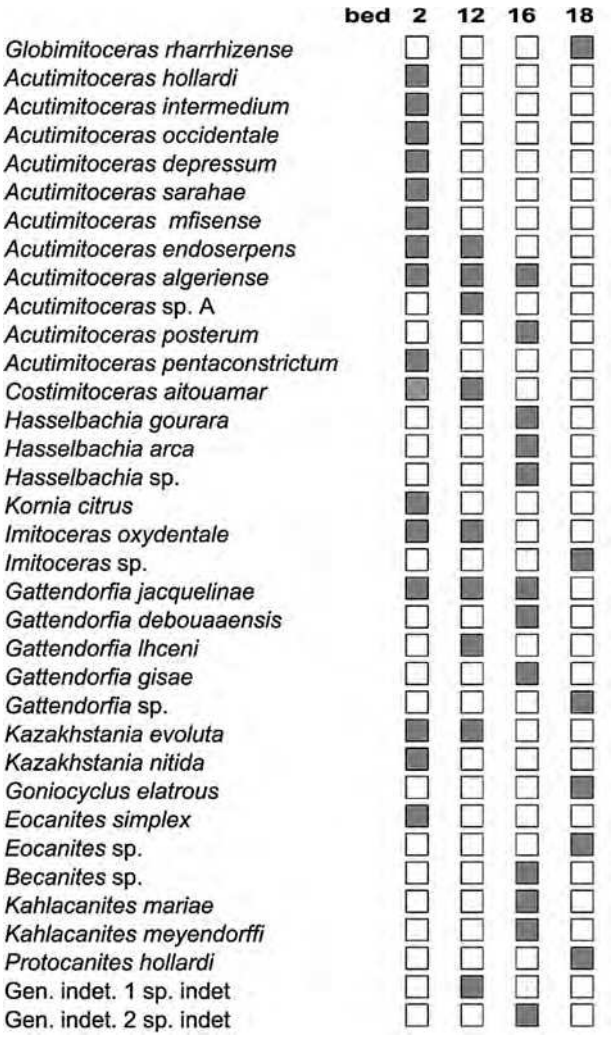

Fig. 31: Ranges of goniatites in the lower/middle Tournaisian of the Aguelmous Syncline (EBBIGHAUSEN & BOCKWINKEL 2007, fig. 3), with the "B & E" bed numbering (see Fig. 30).

X2b of KAISER 2005 and ca. Bed 8 of EBBIGHAUSEN & BOCKWINKEL 2007; Fig. 31). It consists only of species that continue from below, such as *Kornia citrus, Acut. (St.) hollardi, Ac. (St.) endoserpens, Ac. (St.) occidentale, Ac. (St.) sarahae*, and *Eocanites simplex*. It is possible that much of the material was washed in from Fauna 2.

Beds RTB 18-20c (= X1 and X1a of KAISER 2005) are poor in macrofauna. However, somewhat calcareous fine sandstones of Bed RTB 20 (= X1a) yielded *Siphonodella (Eosiphonodella) sulcata* (s.l.), the Carboniferous index conodont (KAISER et al. 2011). Since the species (s.l.) ranges through all of the lower Tournaisian (SANDBERG et al. 1978), it does not help to correlate the goniatite faunas. The area from Beds RTB 20 to 21 is peculiar because large, palaeolithic stone tools (ca. 500 000 years old) are not rare (Fig. 32). Quartzites (strongly cemented sandstones) of the Aguelmous and Fezzou Formations served in several places for tool manufactories. The "first geologists of southern Morocco" were not even *Homo sapiens*.

Fauna 4 from RTB 21 (Bed 12 of EBBIGHAUSEN & BOCKWINKEL 2007, Fig. 31, = Xb1 of KAISER 2005) shows a markedly changed composition. There are small specimens in goethite preservation and larger ones from siderite nodules, including very abundant pleurotomariids, especially from the lower part. Important newcomers include the index species of a regional zone (BECKER in HAHN et al. 2012), *Acut. (St.) posterum*, rather evolute intermediates between *Acut. (Stock.) endoserpens* and *Weyerella protecta* (see Figs. 35k-l), the cadiconic *Gatt. debouaaensis*, and *Gatt. lhceni*. Since the latter species closes its umbilicus at maturity, which excludes it from *Gattendorfia*, BECKER (in HAHN et al. 2012) re-assigned it to the revived genus *Zadelsdorfia*. The Kazakhstan type species of *Zadelsdorfia* also shows a closing umbilicus and rather high, compressed whorls at maturity. A very rare, extremely evolute form with concave venter and laterally shifted U-lobe from Bed RTB 21 (Figs. 35q-r) may link *Kazakhstania* and early members of the *Acrocanites* Group. The associated fauna is rich in gastropods (bellerophontids, pleurotomariids, and others), orthocones, *Aulacella*, and nuculoids. Fauna 5 was collected loose near the marker sandstone Bed RTB 24 (= Bed 13 of BOCKWINKEL & EBBIGHAUSEN 2007). It shows no difference to Fauna 4. The same applies to a few specimens (Fauna 5/6) from just below Bed RTB 26 (top of Bed 14 of BOCKWINKEL & EBBIGHAUSEN 2007 = top of Bed X-1 sensu KAISER 2005). Therefore, all three levels fall in the regional *Acut. (St.) posterum* Zone. A correlation with the German *Paragattendorfia patens* Zone is supported by the co-occurrence of the similar *P. aboussalamae* and *Acut. (St.) posterum* in the eastern Tafilalt (at Mfis, BOCKWINKEL & EBBIGHAUSEN 2006).

The mostly sideritic Fauna 6 from Bed RTB 27 (= Bed 16 of EBBIGHAUSEN & BOCKWINKEL 2007; Fig. 31) differs very strongly from the preceding assemblages. Most characteristic are two species of *Kahlacanites* (Figs. 35s-t), several species of *Hasselbachia* (s.l.), and the rather involute *Gatt. gisae.* Several species of gastropods and orthocones co-occur. HAHN et al. (2012) described from this regional *Ka. mariae* Zone the endemic trilobites *Cyrtoproetus (Crassibole) acrops* and *Diacorypge (Archaeocoryphe) maiderensis*. Outside North Africa, no equivalent of the top lower Tournaisian *Gattendorfia-Kahlacanites* Assemblage (KORN et al. 2007) is known. Therefore, the local goniatite and trilobite records are of highest importance to understand diversity and evolutionary trends around the global Lower Alum Shale Event at the base of the (classical) middle Tournaisian.

At the NW limb of the Aguelmous, the overlying, middle/upper Tournaisian Rharrhiz Formation is mostly covered. The best collecting of its *Goniocyclus* fauna is at the Rich el Mbidia, E of Fezzou (see EBBIGHAUSEN & BOCKWINKEL 2007; Fig. 31).

Fig. 32: Large palaeolithic stone tool made from quartzites of the Aguelmous Formation; length = 13.5 cm (leg RTB).

7. Tazoult

The Tazoult is the elongate, low ridge stretching from the periphery of Fezzou in SW direction (Fig. 3). The measured section (Fig. 33) lies at GPS N 30°55´57,1´´, W 4°54´06.2´´. The easiest access is from the S, after the piste curves to the SW.

At the base of the very gentle northern slope, a level of red siderite concretions without fauna marks the start of the sampled section. Olive-green, silty shales of Bed 1 are very fossiliferous, especially in the upper part. They yielded the pelagic lower Tournaisian Fauna 2 known from Bou Tlidat, locally with:

Dechenelloides tazoultensis
Acutimitoceras (Stockumites) intermedium
Acutimitoceras (Stockumites) depressum
Acutimitoceras (Stockumites) mfisense
Acutimitoceras (Stockumites) sarahae
Acutimitoceras (Stockumites) aff. *sarahae* (thicker)
Acutimitoceras (Stockumites) endoserpens (Figs. 35i-j)
Acutimitoceras ("Stockumites") occidentale
Acutimitoceras ("Stockumites") hollardi
Acutimitoceras (Streeliceras) oxydentale (Figs. 35g-h)
"Acutimitoceras (Stockumites)" algeriense
"Costimitoceras" aitouamar
Kornia citrus (Figs. 35e-f)
Gattendorfia jaquelinae
Eocanites simplex
breviconic nautiloids
orthocones indet.
pleurotomariids

rounded bellerophontids
oxyconic planispiral gastropods
"*Holopella*" sp.
nuculoids
grammysioid
other bivalves
Aulacella sp.
rhynchonellids
other brachiopods
micheliniid corals (Tabulata)
solitary Rugosa

The difference to Fauna 2 of Bou Tlidat is very small but there is a slightly higher diversity (e.g. with the presence of trilobites and tabulate corals) and abundance of benthos whilst the Gattendorfiinae are rarer. The bottom ventilation was slightly better than at the NW limb of the Aguelmous Syncline.

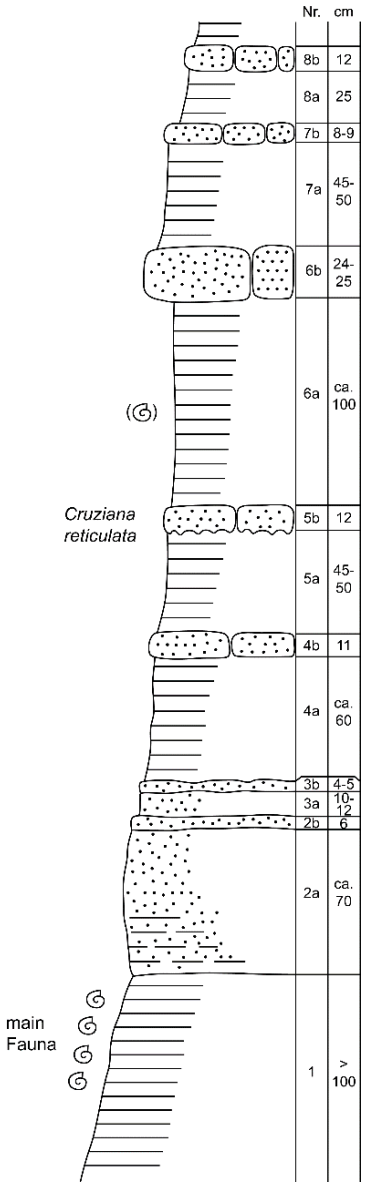

Fig. 33: Section log for the lower Tournaisian at Tazoult, with the position of goniatite faunas and of the *Cruziana* marker bed.

Bed 2 consists of thinly-bedded, micaceous, slightly bioturbated, olive to yellowish-grey siltstones without macrofauna. Beds 3 and 4 represent two thinner cycles of siliciclastic coarsening upwards shedding, with more solid siltstone and fine sandstone, respectively, at the top. Bed 5b is an important marker sandstone, which has partly been excavated. Rapid deposition filled at the base a dense network of straight, large arthropods tracks with fine sand (SEILACHER 2007; KAISER et al. 2011; GEESINK 2013). The traces strongly resemble the middle Givetian *Cruziana reticulata* (LANDING & BRETT 1987) and are too large to have been formed by any of the so far documented Tournaisian trilobite groups of the Anti-Atlas (see HAHN et al. 2012). The bed enables correlation along the Aguelmous Syncline and for more than 100 km eastwards, to the contemporaneous goniatite-rich succession of the eastern Tafilalt Basin (Mfis section, e.g. KAISER 2005; KAISER et al. 2011). It indicates a continuous open marine connection. Therefore, the term Fezzou Formation, in its revised sense, could also be used for the pelagic lower Tournaisian of the Tafilalt Basin (see facies diagram in KAISER et al. 2011, fig. 7). The incredibly dense cover of the muddy seafloor just underneath Bed 5b by tracks and their restriction to a narrow interval, despite similar sediments below and above, reflects an epibole (bloom) of the trace producer. Variable track sizes (Fig. 33) suggest that there was a population consisting of different ontogenetic stages. Whatever palaeoecological factor enabled this regionally wide-spread arthropod population burst, it did not serve the cephalopods and their associated "normal" benthic community.

Fig. 34: Multiple crossing of large (non-trilobite) arthropod tracks (*Cruziana reticulata*) at the underside of Bed 5b at Tazoult.

The olive shales of Bed 6a yielded a sparse, mostly small-sized faunule with a somewhat different

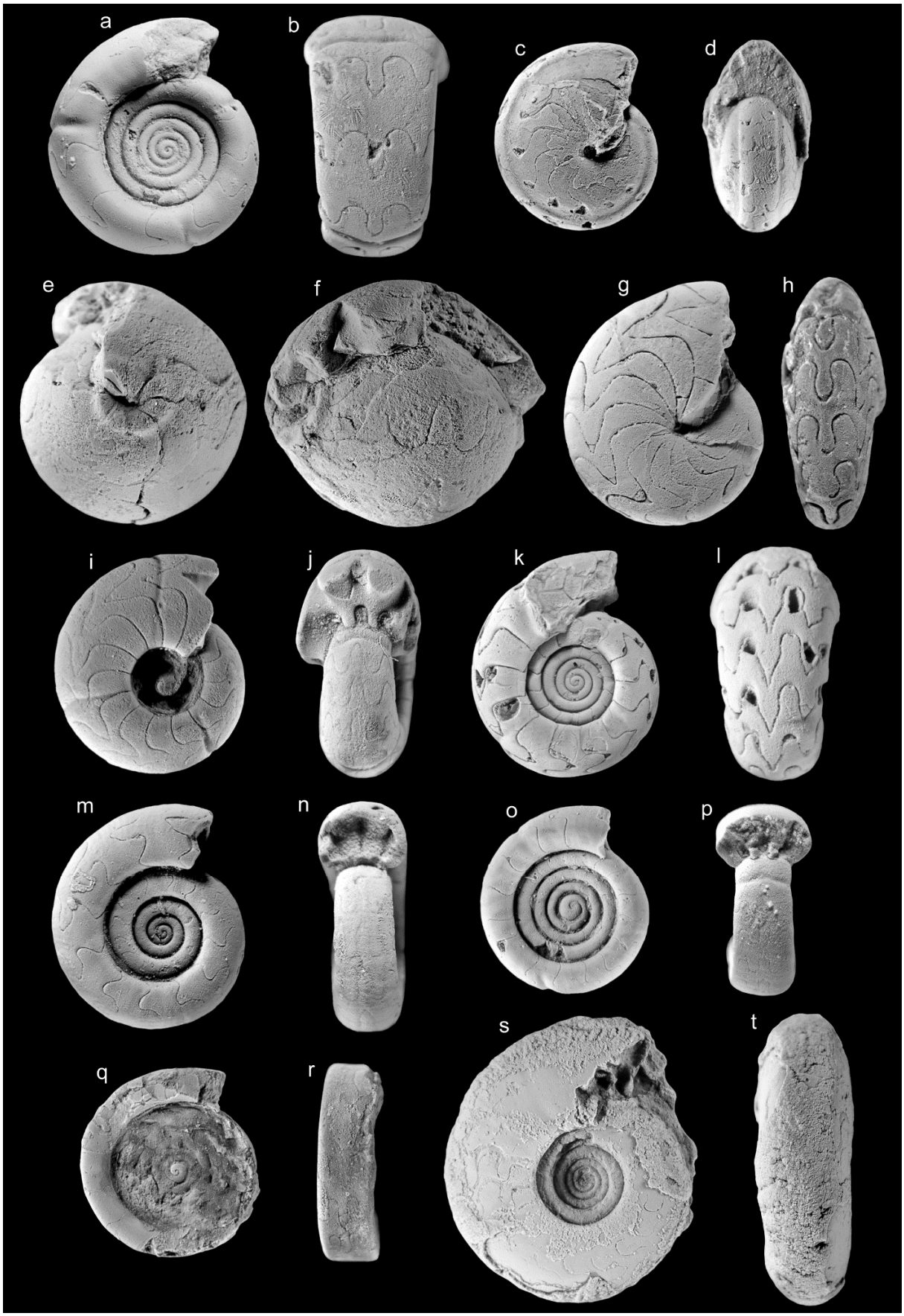

Fig. 35: Lower Tournaisian goniatites from the Fezzou Formation of Bou Tlidat (BTl) and Tazoult (Taz). **a-b.** *Gattendorfia jacquelinae*, BTl, Fauna 2, x 5; **c-d.** *"Costimitoceras" aitouamar*, specimen with very strong ventrolateral furrows, BTl, Fauna 2, x 5; **e-f.** *Kornia citrus*, Taz, Fauna 2, x 4; **g-h.** *Acutimitoceras (Streeliceras) oxydentale*, Taz, Fauna 2, x 4; **i-j.** *Acut. (St.)*

endoserpens, Taz, Fauna 2, x 5; **k-l.** *Acut. (Stockumites)* n. sp., intermediate towards *Weyerella*, BTl, Fauna 5, x 5; **m-n**. *Eocanites simplex*, BTl, Fauna 2, x 5; **o-p.** *Kazakhstania nitida*, BTl, Fauna 5, x 6; **q-r.** N. Gen. aff. *Kazakhstania*. BTl, Fauna 5, x 6; **s-t.** *Kahlacanites mariae*, BTl, Fauna 6, x 3.

composition than in Bed 1. Therefore, it is unlikely that it was washed in from the rich Fauna 2. The current record consists of:

Acutimitoceras (Stockumites) intermedium
Acutimitoceras (Streliceras) cf. *oxydentale* (with rather strong, concave varices)
Gattendorfia jacquelinae
orthocones indet.
Euphemites sp. (possibly the oldest known representative of the genus; compare a similar record from Mfis, Bed 9, in BOCKWINKEL & EBBIGHAUSEN 2006)
different bellerophontid
pleurotomariaceans and planispiral gastropods
nuculoids
Aulacella sp.
?Crurithyris sp. and other brachiopods

Bed 6b is a dark, ca. 25 cm thick marker sandstone that also has been excavated by locals. The overlying alternation of silt- and sandstones did not yield the characteristic Faunas 4 to 6 of Bou Tlidat. This underlines a paleoecological differentiation along strike. In the plain towards the W/SW, there are some outcrops of the mostly deeply weathered Rharrhiz Formation. Decalcified concretions yielded negatives of *Protocanites*, an index goniatite for the middle/upper Tournaisian, *Imitoceras* sp., a poorly preserved ribbed gattendorfiid (related to *Zadelsdorfia* sp. of KORN et al. 2004), and a few bivalves. This faunule falls in the *Goniocyclus-Protocanites* assemblage sensu KORN et al. (2007) or in the regional *Gonio. ammari* Zone of BECKER (in HAHN et al. 2012).

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